NASA AUTHORIZATION FOR FISCAL YEAR 1960

HEARINGS

BEFORE THE

NASA AUTHORIZATION SUBCOMMITTEE

OF THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

EIGHTY-SIXTH CONGRESS

FIRST SESSION

ON

S. 1582

A BILL TO AUTHORIZE APPROPRIATIONS TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION FOR SALARIES AND EXPENSES, RESEARCH AND DEVELOPMENT, CONSTRUCTION AND EQUIPMENT, AND FOR OTHER PURPOSES

APRIL 7, 8, 9, AND 10, 1959

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NASA AUTHORIZATION FOR FISCAL YEAR 1960

TUESDAY, APRIL 7, 1959

U.S. SENATE,
NASA AUTHORIZATION SUBCOMMITTEE OF THE
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The subcommittee met, pursuant to call, at 2:15 p.m., in room 224, Old Senate Office Building, Senator John Stennis presiding.

Present: Senators Stennis, Young of Ohio, Dodd, Cannon, Wiley, Smith, and Martin.

Also present: Max Lehrer, assistant staff director; Everard H. Smith, Jr., counsel; Dr. Glen P. Wilson, chief clerk; and Dr. Earl W. Lindveit, assistant chief clerk.

Senator STENNIS. The subcommittee will come to order, please. I have a very brief statement that I shall read.

This afternoon we will begin hearings on the authorization request for the National Aeronautics and Space Administration for fiscal year 1960.

I believe that all those present in this hearing room recognize the vital importance of the space program. A number of the factors illustrating the significance of the space program—both from a military and a civilian point of view—were touched upon during the hearings held by this committee 6 weeks ago on the NASA supplemental authorization for fiscal year 1959. At that time, however, we did not go into these matters in detail, since we were then interested simply in obtaining enough information to serve as a framework for consideration of the 1959 supplemental authorization request.

For fiscal year 1960, the administration has requested $485,300,000 for the National Aeronautics and Space Administration. In addition, the 1960 budget includes approximately $340 million for the space programs of the Department of Defense and the Atomic Energy Commission, thereby bringing the total to over three-quarters of a billion dollars. Even this does not include the very large sums proposed for missiles and other programs related to space activities.

Dr. Glennan stated during our previous hearings that this is the last year in which NASA would be requesting a budget in the order of one-half billion dollars. He forthrightly told us that he expected the cost of the space program to increase to the $1 billion level within the next 2 years, and that it might cost as much as $2 billion per year in the next 6 to 8 years. Some people feel that even these estimates are very conservative.

It is clear from these figures that our space programs will be expensive. If the Congress and the American people are to support these programs, there must be a clear-cut demonstration of the neces-

sity for expenditures of these large sums. It is the purpose of these hearings to explore these matters in considerable detail so that the record will be clear for all to see.

The hearings on the 1960 NASA authorization request will consist of two major phases. The first phase, which we are starting this afternoon, will explore the technical and scientific aspects of all the important projects included in the current space program. This will present to the American people a comprehensive outline of our current capabilities, of our plans for the future and how we expect to realize those plans.

Once this is done, we will proceed with the second phase, which will consist of a detailed examination of the specific programs proposed for fiscal year 1960 and how they relate to the realization of our longer range plans and programs.

Some of the material to be presented to the committee during these hearings is classified. Of course, these classified matters will be heard by the committee in executive session. To assure that the American people get all the facts possible about the space program, we are going to ask Dr. Glennan to have his staff review this testimony that is taken in executive session, and delete only those matters which cannot be disclosed without adverse effect on our national security. The amended testimony will then be made public as quickly as possible.

Our first witness this afternoon will be Dr. Glennan, Administrator of the National Aeronautics and Space Administration. Dr. Glennan will be followed by Mr. Hyatt and other key members of the NASA staff.

Before proceeding, I would like to observe that we expect Dr. Glennan to testify before this subcommittee again during the second phase of these hearings, at which time we would cover in detail the specific elements included in the fiscal 1960 authorization request.

Dr. Glennan, I understand you have other duties this afternoon, and after you have finished your testimony you may feel free to leave, if you desire.

Doctor, you know the custom of the committee, you need not stand, but I will ask you to be sworn now.

Do you solemnly swear that your testimony here will be the truth, the whole truth, and nothing but the truth, so help you God?

Dr. GLENNAN. I do, sir.

(The biographical sketch of Dr. Glennan follows:)

T. KEITH GLENNAN, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATOR

T. (Thomas) Keith Glennan took the oath of office as Administrator of the National Aeronautics and Space Administration on August 18, 1958, after his appointment by President Dwight D. Eisenhower. He became the first Administrator of the new Government organization after its creation under the National Aeronautics and Space Act of 1958.

As Administrator, Dr. Glennan heads a staff of scientists, engineers, and technicians, and other employees engaged in research and development in aeronautics and space matters. The NASA is an independent agency reporting directly to the President. In his capacity as the principal administrative officer of the NASA, Glennan is a member of the National Aeronautics and Space Council.

Glennan is president on leave of the Case Institute of Technology, Cleveland, Ohio, which he has headed since 1947.

He was born in Enderlin, N. Dak., on September 8, 1905. Dr. Glennan spent most of his youth in Eau Claire, Wis., where he attended high school, worked at a variety of odd summer jobs, and spent 2 years at State Teachers College. In 1927, after working his way through college, Glennan was graduated with honors from the Sheffield Scientific School of Yale University with a degree in electrical engineering.

Following graduation, Glennan became associated with the newly developed sound motion picture industry, and spent 2 years in Europe supervising the installation of sound systems, for the Western Electric Co. He later became assistant general service superintendent for Electrical Research Products Co., a subsidiary of Western Electric. In 1935, he joined Paramount Pictures, Inc., in Hollywood, becoming studio manager in 1939. In 1941 Glennan was associated briefly with Vega Airplane Corp., returning to the motion-picture industry as studio manager of Samuel Goldwyn Studios.

The NASA Administrator joined the Columbia University Division of War Research in 1942, serving through the war, first as Administrator and then as Director of the U.S. Navy's Underwater Sound Laboratories at New London, Conn. For his contributions to research during World War II, he was awarded the Medal for Merit.

At the end of the war, Glennan became an executive of Ansco, Binghamton, N.Y. From this position he was called to the presidency of Case. From October 1950 to November 1952, concurrent with his Case presidency, Glennan served as a member of the Atomic Energy Commission.

While Glennan was president of Case, important progress was made in increasing both the quality and quantity of the faculty, student body, and physical plant. A major building program was initiated thorugh which the floorspace of the campus was more than doubled. Important curricular changes emphasizing the role of the humanities in engineering education were initiated. During his 11-year administration, Case was transformed from a primarily local institution into one that ranks with the top engineering schools in the Nation.

Glennan has been extremely active in national and local affairs. He was chairman of the board of the Institute for Defense Analyses, on the Board of the National Science Foundation, and on the Council on Financial Aid to Education. He was a member of the General Advisory Committee of the Atomic Energy Commission. As chairman of the Metropolitan Services Commission of Cleveland, Glennan was concerned with improving government services in the Greater Cleveland area, and in the development of a $175 million cultural and educational center in that city. He was a trustee of the Cleveland Clinic Foundation. He was a member of the boards of the Cleveland Electric Illuminating Co., the Clevite Corp., Standard Oil (Ohio), and the Harris-Intertype Corp.

Glennan continues as a trustee of Case but has taken a leave of absence from the presidency of the institute to become NASA Administrator. When he assumed his duties with NASA, he resigned from all of his other educational and business obligations.

Glennan is a fellow of the American Academy of Arts and Sciences, and member of Sigma XI, Tau Beta Phi, and Chi Phi. He has been awarded honorary degrees of doctor of science from Oberlin College, Clarkson College of Technology, and John Carroll University, and a doctor of engineering degree from Stevens Institute of Technology and Fenn College.

He is married to the former Ruth Haslup Adams, daughter of the late Dr. Thomas Sewell Adams, eminent Yale professor and tax authority, whom Glennan served as a chauffeur while attending college. He has four children: The eldest, Thomas Keith, Jr., is attending graduate school at the Massachusetts Institute of Technology; Catherine a recent graduate of Swarthmore and now a graduate student in library science at Western Reserve University; Pauline who is about to graduate from high school, and Sarah from junior high school.

Senator STENNIS. Thank you. These other gentlemen will be sworn when we come to them, perhaps more than one at a time.

I have here a letter from Senator Johnson saying that he is introducing the bill today and referring it to us for hearings and consideration, and also a copy of the bill which will be in printed form and available after today. I ask the reporter to insert the letter and the bill in the record at this point.

(The letter and bill referred to are as follows:)

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
April 7, 1959.

Hon. JOHN STENNIS
U.S. Senate, Washington, D.C.

DEAR JOHN: Senator Bridges and I have introduced S. 1582, a bill to authorize appropriations to the National Aeronautics and Space Administration for the fiscal year 1960.

As S. 1582 is a bill coming within the area of responsibility of the NASA Authorization Subcommittee, I would appreciate its early consideration by the subcommittee.

With warm regards.

Sincerely,

LYNDON B. JOHNSON, *Chairman.*

[S. 1582, 86th Cong., 1st sess.]

A BILL To authorize appropriations to the National Aeronautics and Space Administration for salaries and expenses, research and development, construction and equipment, and for other purposes

That (a) there is hereby authorized to be appropriated to the National Aeronautics and Space Administration for the fiscal year 1960 the sum of $485,300,000, as follows:

(1) For "Salaries and expenses", $94,430,000.

(2) For "Research and development", $333,070,000.

(3) For acquisition or condemnation of real property, for plant and facility acquisition, construction, or expansion, and for other items of a capital nature, $57,800,000, as follows:

(A) Langley Research Center, Hampton, Virginia: Alterations to thermal structures tunnel; analytical computing equipment; conversion of gust tunnel to noise research laboratory; conversion of test cells to noise test facility; and heater and vacuum system for gas dynamics laboratory, $4,580,000.

(B) Ames Research Center, Moffett Field, California: Data reduction center and mass transfer cooling and aerodynamics facility, $6,555,000.

(C) Lewis Research Center, Cleveland, Ohio: Ion and plasma jet facility; zero-power reactor; in-pile loop; and approximately 25 acres of land, $6,860,000.

(D) High-Speed Flight Station, Edwards, California: Building additions; analog computing equipment; and terminal guidance facility, $2,805,000.

(E) Beltsville Space Center, Beltsville, Maryland: Central flight control and range operations building; space sciences laboratory; instrument construction and installation laboratory; and utility installations, $14,000,000.

(F) Pacific Missile Range, Point Arguello, California: Launching facilities including flight vehicle assembly and check-out facility with equipment for special experiments, $3,000,000.

(G) Various locations: Global range tracking and communication facilities and equipment; facilities for Rover program; and propulsion development facilities, $20,000,000.

(b) Authorization is hereby granted whereby any of the amounts prescribed in subparagraphs (A), (B), (C), (D), (E), (F), or (G) of subsection (a)(3) may, in the discretion of the Administrator of the National Aeronautics and Space Administration, be varied upward 5 per centum to meet unusual cost variations, but the total cost of all work authorized under such subparagraphs shall not exceed a total of $57,800,000.

SEC. 2. Any amount, not to exceed $500,000, of the funds appropriated pursuant to authorization of subsection (a)(3) of the first section for the construction of facilities described under such subsection may, with the approval of the Bureau of the Budget, be used for the construction of new research facilities or for the modification of existing research facilities not specifically authorized in this Act, if such construction or modification is deemed by the Administrator of the National Aeronautics and Space Administration to be of greater urgency than the construction of any facility authorized by this Act: *Provided*, That upon reaching a final decision to implement, the Administrator or his designee shall notify the Committee on Science and Astronautics of the

House of Representatives and the Committee on Aeronautical and Space Sciences of the Senate of the cost of such construction of new research facilities or the modification of existing research facilities: *Provided further*, That no such funds shall be used for the construction or modification of any facility if funds for such construction or modification have been previously denied by the Congress.

Senator STENNIS. Doctor, you may proceed. We are very glad to have you here.

TESTIMONY OF DR. T. KEITH GLENNAN, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. GLENNAN. Thank you, Mr. Chairman. I want to thank you for this opportunity to present NASA's $485,300,000 budget authorization request for fiscal year 1960.

As you have pointed out, the American people have the right to know why they are being asked to support our space activities; they have a right to know what our objectives in space add up to. They add up to this:

Our national security, the undoubted economic benefits for peoples everywhere, and the advancement of basic knowledge about the earth and the universe, all are deeply involved in our national space program.

I think we are agreed that the United States has the resources, the knowledge, the will—and the duty—to pioneer in the space age. If the rewards of space research are to be realized for the benefit of all mankind, it is imperative that this country lead the way. Our free society has paced the development of science and technology for the benefit of mankind for decades. Challenged now by a totalitarian and determined competitor, we have added reason to pursue vigorously a well-planned and broadly conceived research and development program on a continuing basis of urgency.

I am well aware, however, that since space research is a glamorous and exciting business it is all too easy to find one's head not only in the clouds but well above them. At NASA we are consumed with the infinite possibilities of space but we are determined to base our space program upon facts, not fancies. With this in mind, we will constantly be reviewing our program—and our budgets. It is highly probable that our programs will change rapidly during the first years of effort in this new medium simply because we are opening up a new frontier and most of the ground rules are yet to be worked out and understood.

PRESENT AND FUTURE NASA SPACE PROGRAM ACTIVITIES

In considering NASA's 1960 authorization request, it is well to keep in mind that a great deal of our work is intimately concerned with our national security. While we are charged with direction of all U.S. aeronautical and space research and development except for military projects, our charter makes it clear that we are to work very closely with the armed services and make available to them all developments of military interest.

Active cooperation has militated against friction and duplication of effort between the two agencies principally concerned with space exploration and exploitation.

It is not generally realized, for example, that NASA scientists and engineers are currently hard at work on problems connected with all our major military missiles—problems concerned with warhead heating and stability, stage separation, high energy fuels, to name a few. It is no exaggeration to say that just about every U.S. aircraft and missile has benefited importantly from NASA research.

In the economic realm the return will eventually be substantial. Our Vanguard II satellite, for example, recently demonstrated the feasibility of a weather satellite system which will some day provide round-the-clock, round-the-world weather reconnaissance.

We have all heard that communications satellites may well make transocean television possible and speed up worldwide communications of all kinds. Just the other day the Navy announced it planned to establish an experimental radio communications link between Washington and Pearl Harbor—by way of the moon. Such a system, says the Navy, will be virtually jamproof. Unfortunately, the moon will not always be found in the proper location for transmission at will, but a satellite in a so-called 24-hour orbit should provide the necessary basic element for an operating communications system.

As we set out to explore the universe, we have no way of knowing what to expect, any more than the great explorers of the 15th century knew what they would find when they sailed their little ships out upon the deep Atlantic. But this much is certain: if we don't elect to accept this challenge, others will.

In that excellent little pamphlet, "Introduction to Outer Space," prepared by the President's Science Advisory Committee, we find these lines:

> **How can the results possible justify the cost?**
>
> **Scientific research, of course, has never been amenable to rigorous cost accounting in advance. Nor, for that matter, has exploration of any sort. But if we have learned one lesson, it is that research and exploration have a remarkable way of paying off—quite apart from the fact that they demonstrate that man is alive and insatiably curious. And we all feel richer for knowing what explorers and scientists have learned about the universe in which we live.**
>
> **It is in these terms that we must measure the value of launching satellites and sending rockets into space * * ***

NASA RESOURCES

This is, I submit, one of the most challenging assignments ever given to any generation of Americans. To do its part of the job, NASA has the following resources at present:

More than 8,000 scientists, engineers and administrative workers, most of them inherited from our predecessor organization, the National Advisory Committee for Aeronautics.

Three major research centers—Langley, Lewis, and Ames—in Virginia, Ohio, and California, respectively, as well as the Wallops Island Station in Virginia and the High-Speed Flight Station in California, plus several field offices—all representing a Government investment of $350 million.

The Project Vanguard group—133 scientists under the direction of Dr. John P. Hagen of the Naval Research Laboratory and 25 scientists from other NRL divisions—transferred to NASA by Executive order last fall.

The Jet Propulsion Laboratory at California Institute of Technology in Pasadena with 2,300 scientists, engineers, and supporting personnel transferred to NASA from the Department of the Army a few months ago.

An agreement with the Army Ballistic Missile Agency in Huntsville, Ala., under which it carries out certain NASA assignments.

While our contractual relationships with industry, educational institutions, and the military services will grow, we plan, for the present, to keep NASA to essentially the aforementioned organization plus some personnel expansion in 1960 required in connection with the new Beltsville Space Center and the Wallops Island Station.

Let's turn now to the specifics of this request. We are asking for a fiscal 1960 authorization of $485,300,000, an increase of $101,226,468 over the amount available for fiscal year 1959, including supplemental appropriations now under consideration by the Congress. The 1960 budget falls into three categories: $94,430,000 for salaries and expenses; $333,070,000 for research and development; $57,800,000 for construction and equipment.

SALARIES AND EXPENSES

Nearly $70 million of the first item is for personnel costs and services. It provides for staffing NASA's Washington headquarters, its research centers, field stations, field offices and the Beltsville Space Center, now under construction in Maryland. The sum provides for an increase of 1,027 employees over 1959, bringing the total to 9,988 by the end of fiscal 1960.

Other principal expenditures in the first category include: $11,881,000 for electric power, other utilities, and rental of computers and other electronic equipment; $4,420,540 for contributions to the employees' retirement fund; $3,827,000 for communications services and $3,181,00 for travel.

RESEARCH AND DEVELOPMENT

Next comes the "Research and development" category. In both the scientific and applications programs, the cost of propulsion vehicles is included only where proven units are scheduled to be used. Costs shown below for the development of space vehicles include the provision of a number of test vehicles with which certain of the scientific and applications payloads may be flown.

Expenditures in R. & D. are broken down as follows:

$30,026,500 for aircraft, missile and spacecraft research, including support of the NASA and JPL plants and the cost of research contracts.

$46,743,500 for scientific investigations in space: sounding rockets, $10 million; scientific satellites, $22.8 million; lunar probes, $7,140,000; and deep space probes, $6,803,500.

$15,500,000 for development of meteorological and communications satellite systems.

$73 million for space operations technology: $70 million for Project Mercury, the manned space flight program; $3 million for research into space rendezvous techniques.

$52.2 million for space propulsion technology: solid propellant rockets, $3 million; high-energy propellent rockets, $5 million; the 1- to 1½-million-pound-thrust single-chamber rocket engine, $30.2 million; nuclear rocket engines, $8 million; other types of space propulsion engines, $3 million; and auxiliary power units for space vehicles, $3 million.

$5 million for space systems technology: advanced vehicle systems, $1.5 million; development of recoverable first stage—boster—engines, $1.5 million; and orbiting space laboratories, $2 million.

$11.5 million for tracking and data reduction facilities.

$99,100,000 for space vehicle development: Scout, a four-stage, solid propellent rocket of relatively simple design for a wide range of space research assignments, —2 million; Vega, consisting of a modified Atlas ICBM as the first stage, a modification of the Vanguard first stage as a second stage, and a 6,000-pound thrust third-stage engine now under development, $42.8 million; Centaur, consisting of a modified Atlas as first stage, a high-energy second stage, and the same 6,000-pound-thrust third stage as Vega, $41 million; and Thor-Delta—the Thor-Able with addition of coasting guidance control and a radio guidance system—for general satellite and space probe work, $13.3 million.

Vega, with a potential of placing 5,800 pounds in an earth orbit, or 740 pounds into 22,000-mile orbit, will permit experiments with communications relay satellites. Centaur, which will be capable of putting an 8,400-pound payload into a 300-mile orbit, should be able to place a 730-pound payload on the moon.

CONSTRUCTION AND EQUIPMENT

The third and final category—construction and equipment—is made up of the following items:

$4,580,000 for modernization of facilities at Langley Research Center.

$6,555,000 for a data reduction center and a mass transfer cooling and aerodynamics facility at Ames Research Center.

$6,860,000 for ion and plasma jet facilities, land acquisition, and other items at Lewis Research Center.

$2,805,000 for building additions, analog computing equipment, and a terminal guidance facility at the high-speed flight station.

$14 million for the Beltsville Space Center where the NASA space flight development programs will be planned, controlled and evaluated. It will house the space task group, which is charged with Project Mercury, and the Vanguard, Space Sciences, and Theoretical Divisions.

Of the $14 million figure, $3.3 million will provide a central flight control and range operations building, $6 million will go for a space science laboratory, $3.7 million for an instrument construction and installation laboratory, and $1 million for utility installations.

$3 million for launching facilities, including flight vehicle assembly and checkout facilities, at the Pacific Missile Range, Point Arguello, Calif.

Lastly:

$10 million for global tracking and communications equipment; $2 million for the Rover program and $8 million for propulsion development facilities.

These items constitute the general authorization request. We will go into more detailed justification at the end of our presentation. With this budget we can press forward rapidly and effectively with our space program. At the same time, we must stay on top of new developments and discoveries and be ready to exploit them to the fullest. This is a sound, but forward-looking, budget. With it we can do our job.

Now, Mr. Chairman, this is really a general look at this budget picture. As you can see, we have our technical people here who are ready to give you the technical backup for these general statements, and I shall be very happy to come back here and respond in detail to your questions on our programs.

Senator STENNIS. Doctor, we certainly want to thank you for your appearance and your good statement. We have two phases to these hearings, members of the committee. The first is the technical part that we will begin going into for the remainder of this afternoon, and the second part will be when we come back to the line items, so-called, and budget authorization matters that the doctor covered in the last part of his statement.

Dr. Glennan has already said that he is needed someplace else this afternoon, and is willing to stay as long as needed, but then wishes to retire.

Anyone may, of course, ask any questions he wishes now, then we will go into the technical part. That will be an education in itself, I think. I just want to mention this: I am glad you brought out there the part that this program can play with reference to the weather, and also to the possibilities of communication—all of which are on the constructive side. As I understand it now, these are actively in the program and are being pushed.

Dr. GLENNAN. This is quite right, sir.

Senator STENNIS. As much as any other part of your program.

Dr. GLENNAN. This is quite right, sir.

Senator STENNIS. Senator Young, do you have any questions?

PLANNED AND UNPLANNED DUPLICATION

Senator YOUNG. The only question I would have, Dr. Glennan, concerns your testimony before another subcommittee of this committee in which you spoke of planned duplication and unplanned duplication. Could you, without taking too much time, give us an example of planned duplication and the benefits sought from planned duplication?

Dr. GLENNAN. Yes, I think so. In the area of the communications satellite, Senator Young, we are pursuing vigorously a so-called passive satellite which is a large balloon with a reflecting type of surface; it does not carry with it any electronic equipment.

The ARPA group in the Defense Department are carrying on what they call an active communications satellite, where a satellite is flown which contains electronic equipment able to receive a signal and to repeat that signal continuously or at will on triggering from the

ground to another ground station. In our activities in the communications field, we undoubtedly are going to want to look into the matter of active satellites with respect to their use in commercial systems. It is wholly probable that there will be three or four avenues of research which tend to be duplicating avenues of research, but they are really sufficiently different so that while a person looking at them says, "Well, you are duplicating, you don't have to carry four research programs at the same time," this sort of thing would be planned duplication where we wanted to go down two or three channels in order to assure ourselves we are getting on rapidly and selecting finally the best channel of approach.

In the unplanned duplication, and this is just something that happens and you are on the watch for it at all times trying to avoid it.

Senator YOUNG. In other words, you are doing your utmost and will continue to do your utmost to put an end to unplanned duplication?

Dr. GLENNAN. Without any question. It is just a waste of money.

Senator YOUNG. Well, of course, even planned duplication is more costly; any duplication is costly.

Dr. GLENNAN. Yes, sir.

Senator YOUNG. May I just ask this one further question: before you undertake any planned duplication, is the matter carefully thought out and determined that it is worth the additional cost?

Dr. GLENNAN. Yes. I think one can say that unequivocally, Senator Young. We were in session yesterday with our friends in the Department of Defense looking at some of these programs together, and we are going to look at them even more closely as time goes on.

Senator YOUNG. Are you at all times endeavoring to avoid duplication, if you can?

Dr. GLENNAN. We certainly are, sir.

Senator YOUNG. Thank you.

Senator STENNIS. Mrs. Smith.

Senator SMITH. I have no questions, Mr. Chairman.

Senator STENNIS. Senator Cannon.

Senator CANNON. Thank you, Mr. Chairman. Doctor, I would not like this answer now, but later, during these hearings, I may ask the question again so you may give a little thought to it. As you know, one of the big problems now is the consideration of the budget authorization for the next fiscal year, and I would like to ask you to be prepared to tell us later on during these hearings what, in your opinion, would be the effect of a 10-percent overall reduction in the amount of money that you have requested.

Dr. GLENNAN. Yes, sir.

Senator CANNON. I have nothing further.

Senator STENNIS. Senator Martin.

Senator MARTIN. I have seen evidences of your struggle to avoid duplication, especially out at Edwards Air Force Base. I think that is a good indication of your intent to avoid unnecessary duplication at every step of the way. There are places in the defense picture where we are going to have to put a lot of time and energy to head it off. What I have in mind is the high altitude atomic explosion and its effect on communications particularly. There we are going to have

to work in close cooperation. I don't know which one is going to do the most important work. We are all going to have to work on that one.

Dr. GLENNAN. Yes, sir.

Senator MARTIN. I have no further questions.

Senator STENNIS. Senator Wiley, do you have any questions?

DISCUSSION OF WORK OF NICHOLAS CHRISTOFILOS

Senator WILEY. I want to know if this gentleman can tell me what Christofilos did.

Dr. GLENNAN. Christofilos?

Senator WILEY. Yes.

Dr. GLENNAN. In what way?

Senator WILEY. I want to know what he put over on the experts. In other words, the experts knew everything and finally they had to admit that he knew something, too.

Dr. GLENNAN. He predicted the results.

Senator WILEY. Yes, he did.

Dr. GLENNAN. Which came——

Senator WILEY. What were those results?

Dr. GLENNAN. I cannot describe that, but perhaps some of our technical people can give you more of an answer to that in due course, Senator Wiley.

Senator WILEY. I know, but what effect did it have on our present knowledge of this thing we are studying?

Dr. GLENNAN. I think I would rather defer to one of our technical people here.

Senator STENNIS. We are going to have the technical witnesses in just a few minutes, Senator, and it might be better if it were referred to them.

Dr. GLENNAN. Mr. Chairman, may I indicate that this was a project that was not carried out by our agency, as you probably know.

Senator WILEY. I know, but you fellows are supposed to get acquainted with the results in other agencies.

Dr. GLENNAN. Yes.

Senator WILEY. We can't be going off on a tangent here—spending a half-million dollars—until we know what we are doing. What I am trying to find out is whether or not what he and the rest of them arrived at—whether it had any effect on what you are going to do here.

Dr. GLENNAN. No, sir.

Senator WILEY. Why not?

Dr. GLENNAN. Because this is a temporary phenomenon which was occasioned by a single expert, and it would have no lasting effect on the radiation belt in the upper atmosphere that would affect what we are attempting to do at all.

Senator WILEY. Can you tell me briefly just what you are attempting to do?

Dr. GLENNAN. We are attempting to explore outer space, to understand the phenomena that we may find there. We are attempting to get on with the problems of developing certain of those activities which will turn into commercially feasible projects, such as the weather prediction, perhaps in time weather modification, which will

probably give us a very usable and very necessary communications capability.

Senator WILEY. One other question, Mr. Chairman. Can you tell me briefly what you feel has been accomplished by Christofilos and his suggestions?

Dr. GLENNAN. Well, I think that any man who can add to the knowledge that we possess in all of these areas of science has made a very real contribution to mankind. After all, the kind of world we live in today has been developed largely out of the work of men just like him.

Senator WILEY. All right.

Senator STENNIS. Thank you, Senator. Doctor, we thank you again for being here.

Dr. GLENNAN. Thank you very much.

Senator STENNIS. We know the circumstances which force you to leave.

Dr. GLENNAN. Thank you, sir.

Senator STENNIS. We have several witnesses, members of the committee, for the technical phases for this afternoon's hearing. May I ask these gentlemen to rise when their names are called and be sworn: Mr. Hyatt, Mr. Stoney, Mr. Rosen, Mr. Moeckel, Mr. Childs, Mr. English, Mr. Finger, Colonel Appold, Mr. Tischler, and Colonel Armstrong. The last three gentlemen will testify in executive session.

Do each of you solemnly swear that your testimony here will be the truth, the whole truth, and nothing but the truth, so help you God?

Mr. HYATT. I do.

Mr. STONEY. I do.

Mr. ROSEN. I do.

Mr. MOECKEL. I do.

Mr. CHILDS. I do.

Mr. ENGLISH. I do.

Mr. FINGER. I do.

Colonel APPOLD. I do.

Mr. TISCHLER. I do.

Colonel ARMSTRONG. I do.

(The biographical sketches of the witnesses follow:)

ABRAHAM HYATT, ASSISTANT DIRECTOR FOR PROPULSION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Abraham Hyatt joined the headquarters staff of the National Aeronautics and Space Administration in October 1958, as Assistant Director for Propulsion in the Office of the Director of Space Flight Development. Programs under his direction include the development of rocket vehicles, solid- and liquid-fuel rocket engines, nuclear engines, and space propulsion.

Before joining the NASA staff, Hyatt was chief scientist and research analysis officer of the Navy's Bureau of Aeronautics. He is noted for his work on high-energy fuels and on research which led to development of the Navy's Skystreak and Skyrocket research airplanes, the Lark and Polaris missiles, and the verticle-takeoff airplane.

Hyatt was born in Ukraine, Russia. He came to the United States as a small boy and became a naturalized citizen in 1927. He earned a bachelor of science in aeronautical engineering degree from Georgia Institute of Technology in 1933. During World War II, he served in the U.S. Marine Corps. He currently holds the rank of lieutenant colonel in the Marine Reserve.

Hyatt is married to the former Grace Holladay. Mr. and Mrs. Hyatt and their daughter Sherry Anne, 10, live at 1716 Connecticut Avenue NW., Washington, D.C. Their other daughter, Mrs. Linda Lauve, lives in Monterey, Calif.

W. E. STONEY, JR., SUPERVISORY AERONAUTICAL RESEARCH ENGINEER, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

William E. Stoney, Jr., is an aeronautical research engineer in the Pilotless Aircraft Research Division of NASA's Langley Research Center, Hampton, Va. Currently he is in charge of designing the Scout, a four-stage, low-cost rocket vehicle currently under development.

Mr. Stoney joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1949, at the Langley facility. Since that time he has been engaged in aeronautical research in the Pilotless Aircraft Research Division.

Born in Terre Haute, Ind., in 1925, Mr. Stoney earned a bachelor of science degree in aeronautical engineering from Massachusetts Institute of Technology in 1949, and a master of science in aeronautical engineering from the University of Virginia in 1951.

In the field of aerodynamics, Mr. Stoney has specialized in research in aerodynamic drag and heat transfer frequently involving the flight test of rocket vehicles launched from Wallops Island, Va.

Mr. and Mrs. Stoney, Jr. (the former Roberta Beckner) live at 303 LaSalle Avenue, Hampton, Va.

MILTON W. ROSEN, CHIEF, ROCKET VEHICLE DEVELOPMENT PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Milton W. (William) Rosen was appointed chief of the rocket vehicle development program in the Office of the Assistant Director for Propulsion, National Aeronautics and Space Administration, on October 20, 1958. Previously, on the staff of the U.S. Naval Research Laboratory, he was technical director of project Vanguard, the scientific earth satellite program.

Rosen is a native of Philadelphia, Pa. He earned a bachelor of science degree in electrical engineering from the University of Pennsylvania in 1937.

He joined the staff of the Naval Research Laboratory in 1940. During World War II he worked on guidance systems for guided missiles. From 1947 to 1955 he was in charge of the Viking rocket development, and was head of the rocket development branch. He was technical director of project Vanguard from 1955 until his appointment to the NASA headquarters staff.

Rosen has specialized in research in the fields of electronics, guidance, and rocket propulsion. In addition to numerous articles on rockets and space flight in technical journals, he is the author of "The Viking Rocket Story," published by Harper & Bros. in 1954. Also in 1954 he won the James H. Wyld Memorial Award of the American Rocket Society for his work in the application of rocket power. Rosen is a member and former director of the American Rocket Society.

Mr. and Mrs. Rosen (the former Josephine Haar) and their three daughters live at 2505 Fairlawn Street, Hillcrest Heights, Md.

WOLFGANG E. MOECKEL, CHIEF, ADVANCED PROPULSION DIVISION, LEWIS RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Wolfgang E. Moeckel, as Chief of the Advanced Propulsion Division at the NASA's Lewis Research Center, Cleveland, Ohio, is responsible for research on electric and other nonchemical propulsion systems. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1941.

Born in Germany in 1922, Moeckel came to the United States in 1927 and became a naturalized citizen 2 years later. He attended grammar and high schools in Dearborn, Mich. He earned a bachelor of science degree in physics from the University of Michigan in 1944.

After joining the NACA as an aeronautical research scientist Moeckel performed research on reciprocating engines, small rockets, and supersonic aerodynamics until 1949. The next year he was named head of the Boundary Layer Section where he studied supersonic boundary layer phenomena.

From 1950 to 1955, Moeckel was Chief of the Special Projects Branch, involved in research in aerodynamic heating and supersonic and hypersonic ramjet engines. During the next 3 years he was Assistant Chief of the Pro-

pulsion Aerodynamics Division, engaged in research in hypersonic aerodynamics, aerodynamic heating, and space propulsion systems. In 1958 he was appointed to his present position.

Moeckel is a member of the American Rocket Society and the Institute of the Aeronautical Sciences. He is the author of numerous technical papers and articles.

Mr. and Mrs. Moeckel (the former Betty Miller) and their one son live at 524 Canterbury Road, Bay Village, Ohio.

J. HOWARD CHILDS, CHIEF, ELECTRIC PROPULSION BRANCH, LEWIS RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

J. Howard Childs has been Chief of the Electric Propulsion Branch of NASA's Lewis Research Center, Cleveland, Ohio, since 1958. He is a specialist in combustion and electric propulsion.

Childs is a native of Bartow, Fla. He earned a bachelor of science degree in chemical engineering in 1943, and a master's degree in engineering in 1947, both from the University of Florida.

He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1944 as an aeronautical research scientist at the Lewis facility in Cleveland.

In 1946 he was made head of the Jet Engine Combustion Section and 4 years later was appointed Chief of the Section. He assumed his current position at the Lewis Research Center in 1958.

Childs is the author of numerous technical papers and is a frequent contributor to technical journals .

Mr. and Mrs. Childs (the former Mary Sulkowski) and their three daughters live at 7474 Columbia Road, Olmsted Falls, Ohio.

ROBERT E. ENGLISH, ASSOCIATE CHIEF, POWER PRODUCTION AND SHIELDING BRANCH, NUCLEAR REACTOR DIVISION, LEWIS RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Robert E. English, 38, joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, as a mechanical engineer at Lewis Research Center, Cleveland, Ohio, in 1944.

While in the Compressor and Turbine Research Division at the Lewis facility, he made important research contributions in turbine aerodynamics and multistage turbines. He also served as a consultant to that Division on performance and design, parameters of compressors, and turbine requirements.

He is the author of numerous technical reports and articles for technical journals.

English earned bachelor and master of science degrees in mechanical engineering from the University of Minnesota in 1941 and 1947. From 1941 to 1944 he was an instructor of mechanical engineering at the university.

Mr. and Mrs. English and their three children live at 2823 West 217th Street, Cleveland, Ohio.

HAROLD B. FINGER, CHIEF, NUCLEAR ENGINES PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Harold B. (Ben) Finger was appointed chief of the nuclear engines program in the Office of the Assistant Director for Propulsion when the National Aeronautics and Space Administration was established on October 1, 1958. Previously he was head of the Nuclear Radiation Shielding Group at the Lewis Flight Propulsion Laboratory of the National Advisory Committee for Aeronautics, the predecessor of the NASA.

Finger joined the NACA in 1944 as an aeronautical research scientist at the Lewis facility in Cleveland, Ohio, where he remained until his appointment to the NASA headquarters staff. In 1952 he was named head of the Axial Flow Compressor Section and in 1954 was named Associate Chief of the Compressor Research Branch. Three years later he was made head of the Nuclear Radiation Shielding Group.

A native of New York City, Finger earned a bachelor's degree in mechanical engineering from City College of New York in 1944. He was awarded a master of science degree in aeronautical engineering from Case Institute of Technology in 1950.

Finger has specialized in research in the fields of turbo machinery, nuclear rockets and shielding. He is the author of numerous technical papers, and was cowinner of the SAE Manley Award for the best paper on aeronautics presented during the Society of Automotive Engineers Day in 1957. He is a member of the Institute of the Aeronautical Sciences.

Mr. and Mrs. Finger (the former Arlene Karsch) and their three children live at 6908 Millwood Road, Bethesda, Md.

COL. NORMAN C. APPOLD, ASSISTANT TO DEPUTY COMMANDER OF WEAPONS SYSTEMS, HEADQUARTERS, AIR RESEARCH AND DEVELOPMENT COMMAND, DEPARTMENT OF THE AIR FORCE

Col. Norman C. Appold was born in Detroit, Mich., on April 3, 1917. He attended Valparaiso University, Valparaiso, Ind., and was graduated with a master's degree in chemical engineering from the University of Michigan in 1941.

He enlisted as an aviation cadet in July 1941, and was commissioned a second lieutenant in the U.S. Army Air Corps in 1942. He served overseas in the Middle East and European theaters from mid-1942 to September 1944, flying B–24's in combat.

Colonel Appold attended graduate school at the California Institute of Technology from 1946 to 1947. He was graduated with a master's degree in aeronautical engineering.

He was assigned to the staff of the Deputy Chief of Staff, Development, Headquarters USAF, from 1947 to 1951, where he specialized in aeronautical and aircraft propulsion work. He then served as chief of the powerplant laboratory, Wright Air Development Center, Dayton, Ohio, until 1956.

Colonel Appold served as Chief of Special Projects for the Deputy Commander, Weapons Systems, at the Air Research and Development Command Headquarters from 1956 to 1957. Since that time he has been Assistant to the Deputy Commander of Weapons Systems.

A. O. TISCHLER, CHIEF, LIQUID FUEL ROCKET ENGINES PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A. (Adelbert) O. Tischler was appointed chief of the liquid fuel rocket engines program in the Office of the Assistant Director for Propulsion, when the National Aeronautics and Space Administration was established on October 1, 1958. Before joining the NASA headquarters staff, he was head of the Rocket Combustion Section at the Lewis Laboratory, in Cleveland, Ohio.

Tischler joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, as a chemical engineer on the staff of the Lewis Laboratory, in 1942. He remained at this research center until he was named to his current post in Washington, D.C. Throughout his scientific career, he has specialized in combusion research, with particular emphasis on turbojet and rocket engines.

A native of Cleveland, Tischler attended local grammar and high schools. He earned a bachelor of science degree in 1940 and a master of science in chemical engineering degree in 1946 from Case Institute of Technology.

Tischler is a member of the American Rocket Society, the Institute of the Aeronautical Sciences, and the Combustion Institute. He is the author of numerous technical papers.

Mr. and Mrs. Tischler and their three children, Craig G., 5, Marc A., 4, and Sandra L., 2, live at 4805 Broad Brook Drive, Bethesda, Md.

COL. JACK L. ARMSTRONG, CHIEF, MISSILES PROJECT BRANCH, OFFICE OF ATOMIC NUCLEAR POWER, AIR RESEARCH AND DEVELOPMENT COMMAND, DEPARTMENT OF THE AIR FORCE

Col. Jack L. Armstrong was born in Winnipeg, Canada, in 1911. He earned a bachelor of science degree in civil engineering from the University of Minnesota in 1933.

He served in the U.S. Army in the Pacific theater from 1941 to 1944. For the next 3 years he was in the Air Transport Command and was ultimately named Deputy Assistant Chief of Staff for Supplies and Services.

Colonel Armstrong was next assigned to the Armed Forces special weapons project as commander of an Air Force special weapons assembly squadron, and later as commanding officer of two atomic weapons storage facilities—first at Gray Air Force Base, Killeen, Tex., and later at Monzano Base, Albuquerque, N. Mex.

From 1952 to 1956 he was Executive, Assistant Director, and later Deputy Director of the Division of Military Application, U.S. Atomic Energy Commission.

Since 1956 Colonel Armstrong has been Chief of the Missiles Branch and Deputy Director of Aircraft Reactors. He also serves as Deputy to Maj. Gen. D. J. Keirn in his capacity as Deputy for Nuclear Systems in the Office of the Assistant Chief of Staff, Development, U.S. Air Force.

Senator STENNIS. Our next witness is Mr. Hyatt. Do you have a prepared statement?

Mr. HYATT. No; I do not. I will merely introduce the witnesses.

Senator STENNIS. Very well. You may proceed in your own way.

TESTIMONY OF ABRAHAM HYATT, ASSISTANT DIRECTOR FOR PROPULSION, NASA

Mr. HYATT. I would like to state that we have a cross-section of the NASA propulsion program divided up into several individual presentations, and we define propulsion here somewhat loosely in that we don't limit it to just the engine but include the vehicle as well. We have presentations on three examples of vehicles that are proposed in the national program.

Our first witness——

Senator STENNIS. May I interrupt for just a moment?

Mr. HYATT. Yes, sir.

Senator STENNIS. As the members of the committee have observed, we have a number of top technical people here with their exhibits, which will take a great deal of time. I think if we can let them present their matters—three or four of them—and make any notes on any question we may wish to ask and then go back and have questions, it will greatly help.

All right, without objection that will be the procedure by the Chairman. Proceed, Mr. Hyatt.

Mr. HYATT. Our first presentation is on Project Scout. This is a simple multipurpose vehicle. The presentation will be made by Mr. W. E. Stoney, who is the head project engineer, and he is working down at the NASA Langley Research Center.

Mr. Stoney.

Senator STENNIS. All right, Mr. Stoney, come forward now and proceed in your own way.

TESTIMONY OF W. E. STONEY, JR., SUPERVISORY AERONAUTICAL RESEARCH ENGINEER, PILOTLESS AIRCRAFT RESEARCH DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. STONEY. Project Scout, as he said, is a simple lightweight vehicle. You have heard and will hear at these meetings of larger and larger vehicles required for larger and larger payloads including men around the sun and around the earth, and we will have a very good reason for having a small economical vehicle, which Project Scout is, to fulfill.

PROJECT SCOUT

The project, when we say a small vehicle capable of placing a hundred or 200 pounds of instruments into orbit around the earth, and capable of doing a variety of other test jobs that have been done by rockets in the past. These smaller rockets have a versatility factor over larger rockets. You can design the orbit that you want to fit exactly the payload you are placing in them, since you probably only have one or two experiments per shot and can get a lot more out of your experiments.

Also, they are cheap enough so that you can plan to do the experiments again once you have gotten the initial information and designed it better to do a more detailed job the next shot.

The Scout I can best describe by showing you this model. This is the vehicle system itself. It is made up of four solid fuel rockets. The different colors represent the different rockets. This is the first, the second, the third, and then the fourth stage we have divided, half of it represents the payload department. It works as follows:

SCOUT LAUNCH OPERATION

The first stage takes it off the ground, and after it burns out the second stage fires, and the first stage is left behind. The second stage fires and burns, and when it has used up all its fuel it is left behind when the third stage fires. Finally, sometime during this period when the third stage fires, we get rid of all this extra weight up here on the front because we don't need it any longer to protect the rest of the missiles from the heat, and we have this attached to the fourth stage, and then the two stages coast up to the peak altitude which has been planned ahead of time, and, during this time, guidance system in the third stage orients the body so that it is horizontal to the earth.

If we want to orbit, and then little spin rockets, I don't know whether you can see them in the little red thing on the side of that table here, are ignited and spin the last stage up rapidly, and then the last stage is ignited and the third stage is left behind, and the fourth stage goes into orbit.

If we want to use the vehicle for reentry tests of advanced war heads, why then we just make the guidance system, point it downward, and then do the same thing, spin it up and fire it in. This is how we will be using it.

SCOUT MOTORS

The Scout uses solid fuel motors. You will hear a lot about liquid motors in these largest vehicles, and you have seen them in the past. We have found in the history of NASA with research rockets that solid fuel rockets have some very fine advances there. They are extremely reliable in operation and simple in operation, and you can operate vehicles which operate simply with them, and they are easy to prepare for launching and to put in action.

The Scout itself has been developed out of a series of vehicles which Langley Laboratories of the NACA–NASA now have been using for years. Shown on this chart are several of these with the Scout itself on the bottom. These vehicles started in 1955 with a four-stage vehi-

cle capable of 6,000 miles per hour; then in 1957 we had a five-stager capable of 10,000; last year we increased that, as better rockets became available, to 12,000 miles an hour; and now we are planning with a Scout which has a capability of 25,000 miles an hour, and we plan to fire the early test shots in the early part of 1960.

UTILIZATION

The Scout not only increases our speed in testing range, which is perhaps extremely valuable, but it also allows us to carry a lot more payload. These vehicles here were very small and only carried about 20 to 25 pounds of instruments. The Scout, however, will carry 100 up to 200 pounds of instruments.

This will increase our capability of making scale tests of reentries, advanced Dynasoar concepts, manned capsule type in reentering, do all the tests which all these things have been doing in the past for us with the smaller models.

Also we will be able to use this system in vertical probes. This type of testing was done with this particular series of models here. In fact, the Air Force used this design in part of their Christofilos experiment, in Project Argus. They carried payloads up to measure what would happen, and this vehicle can be used for the same thing. Of course, this vehicle here, for instance, was capable of going 500 miles with 2 pounds, and the Scout will be able to go 12,000 miles with 1,000 pounds or 25,000 miles with 500 pounds.

This shows the orbits possible. We show here the earth with the Van Allen radiation belt sketched weirdly as a doughnut. Then we show two different types of orbits. First, the ones in the blue type colors are what we call polar orbits. This means we can fire this vehicle in a north-south direction and achieve orbits, if we want a circular orbit, of 1,200 miles; and if we want to sweep out a larger area in the space around us, we can fire it so that the near point of the orbit is about 200 miles, and we can reach out to 8,000 miles at the peak. This, of course, can be in any area. If we take advantage of the earth's rotation we can get an orbit which is again 200 miles down here, but with this extra speed will go out 15,000 miles. As you see, these orbits cross and recross, and are generally in the radiation belt which is an area in the near space which we are very interested in experimenting in.

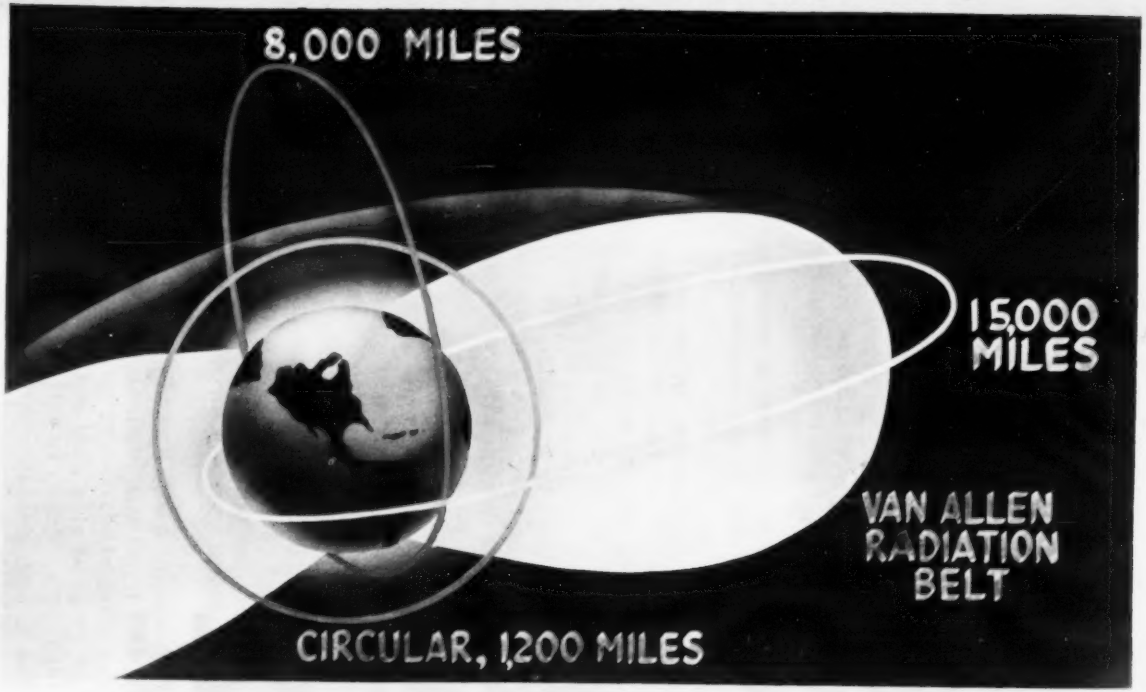
In addition to the space, what you might call space science type experiment which the Scout will provide us capabilities for, it will do the more practical type of things like it will carry even the better cloud-covering experiments than the Vanguard has been able to carry because it has a higher weight capability. It will enable us to make earlier experiments with these communications satellites, and it will also enable us to make experiments with devices such as stabilization systems, which will become part of really large satellites in the future. We will be able to put them up and try them out in Scout first.

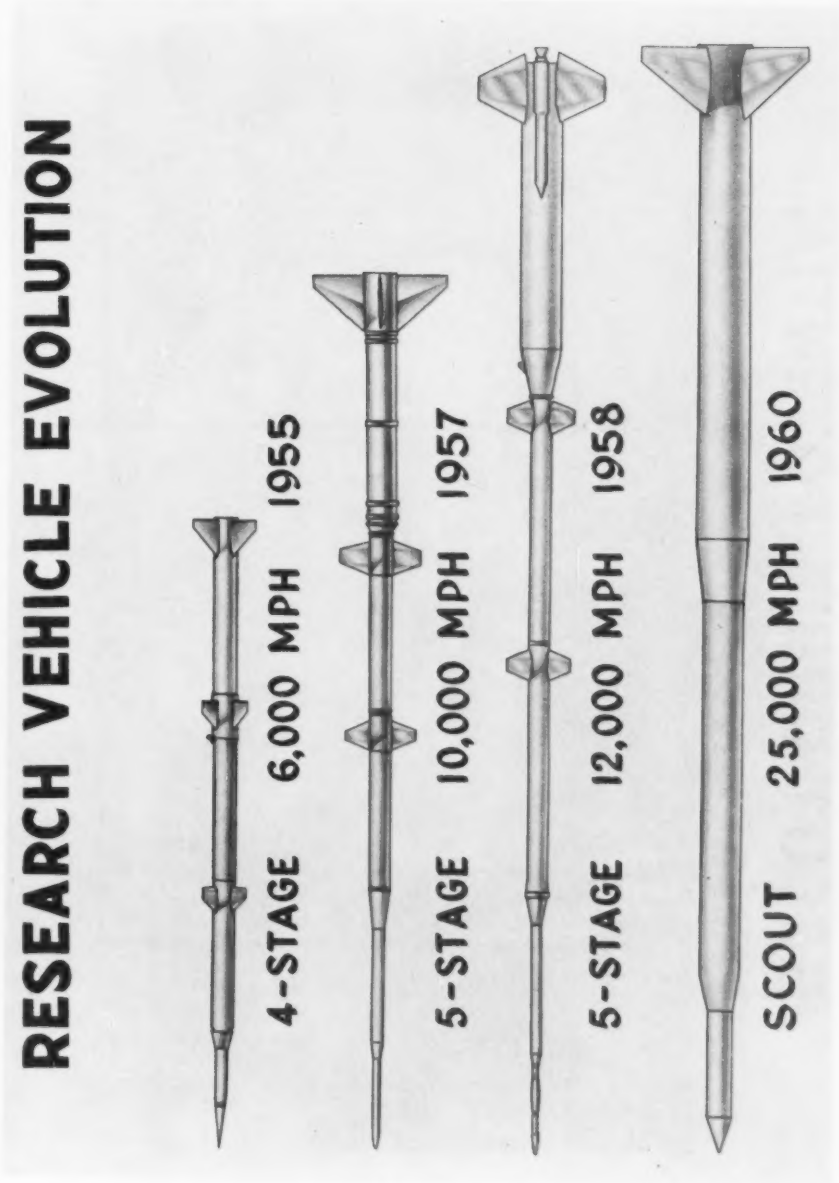
This, I think, completes the story on Scout. The Scout, in summary, is a four-stage solid fuel vehicle designed to give NASA an economical and versatile vehicle capable of doing a variety of space science and reentry experiments.

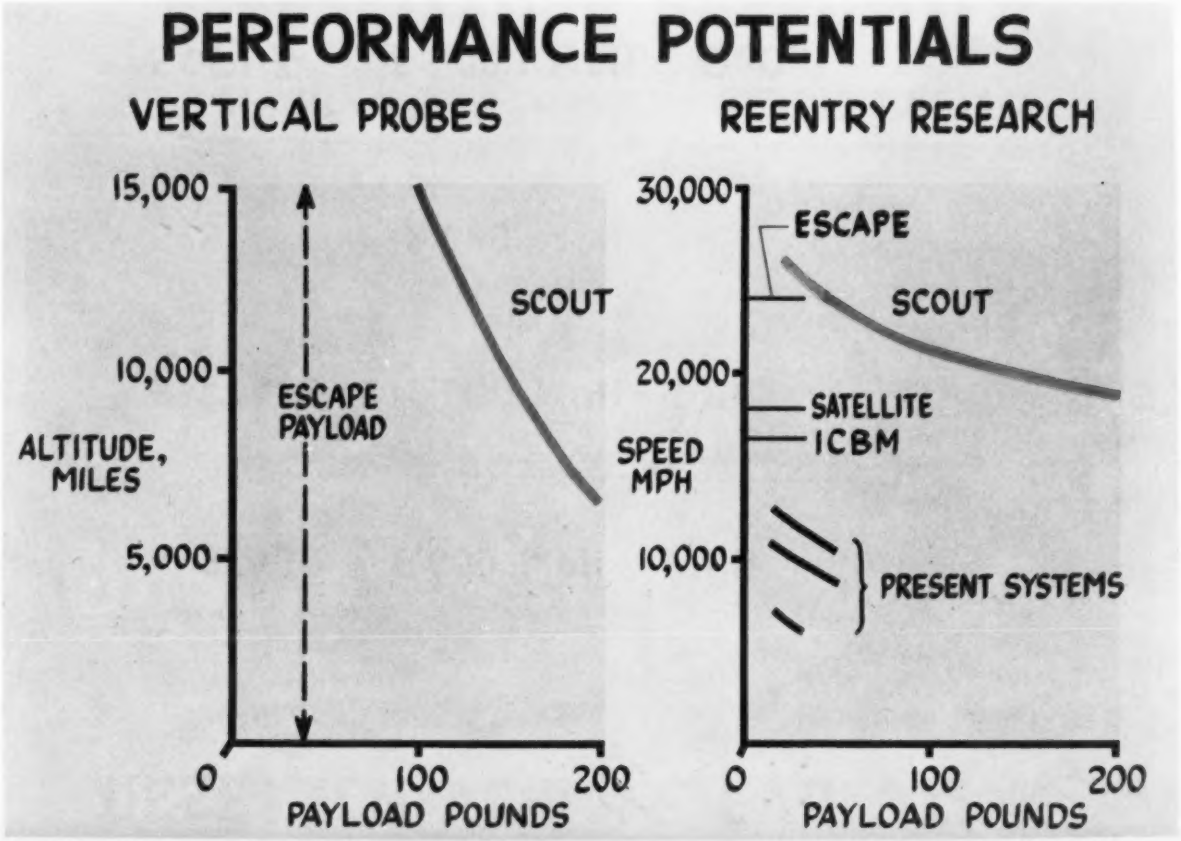
PROJECT SCOUT

SCOUT ORBIT POTENTIAL

PAYLOAD=100 LBS. OF INSTRUMENTS



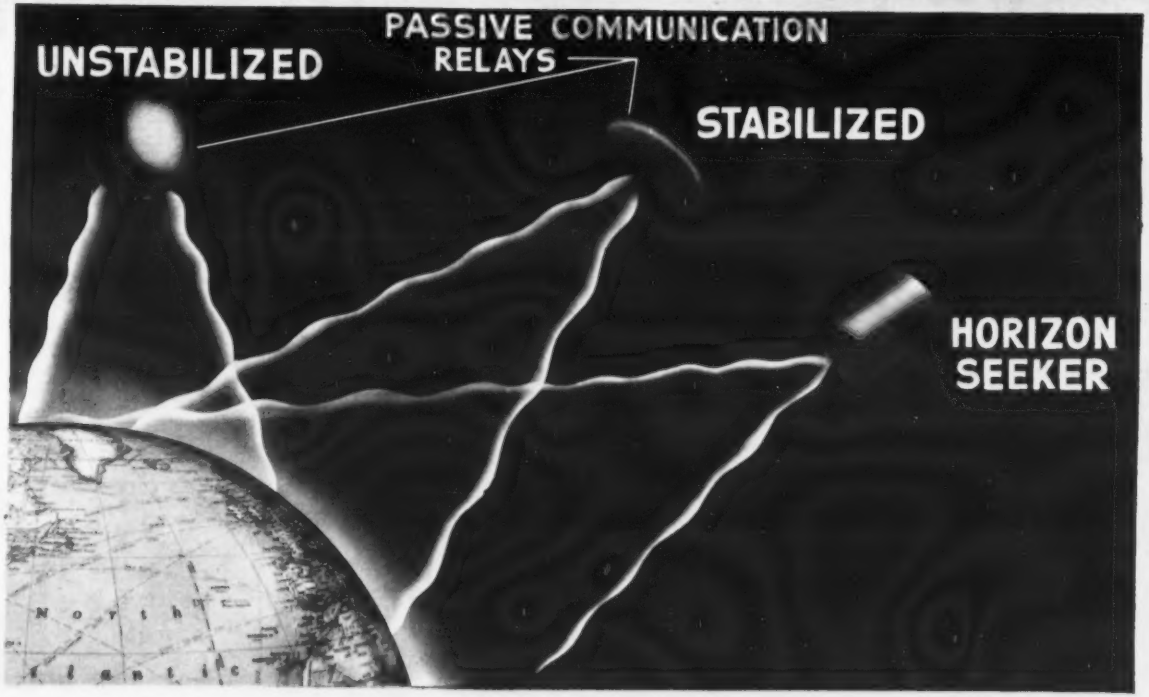

RESEARCH VEHICLE EVOLUTION
4-STAGE 6,000 MPH 1955
5-STAGE 10,000 MPH 1957
5-STAGE 12,000 MPH 1958
SCOUT 25,000 MPH 1960


PERFORMANCE POTENTIALS
VERTICAL PROBES
REENTRY RESEARCH
15,000
10,000
5,000
ALTITUDE, MILES
ESCAPE PAYLOAD
SCOUT
0
100
200
PAYLOAD POUNDS
30,000
20,000
10,000
SPEED MPH
ESCAPE
SCOUT
SATELLITE
ICBM
PRESENT SYSTEMS
0
100
200
PAYLOAD POUNDS

PAYLOAD POUNDS

PAYLOAD POUNDS

RESEARCH ON SPACE SYSTEMS AND COMPONENTS



Mr. HYATT. Mr. Chairman, the next witness will discuss Project Vega.

Senator STENNIS. Let Mr. Stoney be available now, and keep your instruments there, so we can refer back to you. All right, Doctor.

Mr. HYATT. The next witness will present Project Vega, which you might say is truly a second generation type of vehicle. Mr. Milton W. Rosen, Chief of the Rocket Vehicle Development of NASA Headquarters, will make the presentation.

Senator STENNIS. All right, Mr. Rosen, proceed in your own way.

TESTIMONY OF MILTON W. ROSEN, CHIEF, ROCKET VEHICLE DEVELOPMENT PROGRAM, NASA

Mr. ROSEN. Mr. Chairman and gentlemen, one of our problems with the present generation of space vehicles is that these vehicles were put together rather hurriedly to meet the threat of foreign competition, and as a result most of these vehicles were designed for one specific mission—either to put a payload in orbit around the Earth or to send a very small payload out toward the Moon. As a result of this situation, we have tried only a few models of each type. Some of them have succeeded and some have not; then we call upon another vehicle to take the stage. In this situation it is very difficult to obtain any high degree of reliability in any one single vehicle type. Therefore, we have attempted in our national vehicle program presented to the Space Council to introduce what we feel is a new concept—that we can design a vehicle and make it versatile enough to perform the majority of space missions we are going to attempt in a 3- or 4-year period. So that we will have what can be called a general-purpose space vehicle. By firing this one vehicle again, and again, and again for all of the missions, we would hope eventually to achieve a high degree of reliability, and that most of our attempts would be successful.

THE VEGA ROCKET VEHICLE

The first vehicle of this type is called Vega, and it is one that we hope to have in a very short time. With this in mind, we have based it very heavily on existing technology. It comes in either a two- or a three-stage version. The first stage is a production-type Atlas; and the second stage, as we will see, is very heavily based on Atlas technology, using the same tooling, for instance, as the Atlas.

The next chart shows a comparison between the existing Atlas and the Vega, and you will notice that they look very much alike. There is a slight modification to the Atlas. The forward end is brought straight up to the full 10-foot diameter, and then the second stage is mounted on top of it. It is a full 10-foot stage. Where we require the third stage, it is mounted on top of the second. The vehicle is slightly higher than the Atlas, but it can use the same launching sites as Atlas, a lot of the same test equipment as Atlas, and it can use the Atlas production facilities.

The next chart shows a new element in the Vega, that is, the second stage engine shown here on the second stage tankage. This is not a new engine. It is the Vanguard first stage engine, the engine that

has had the best record of performance in Vanguard—in its last six flights its performance has been fully successful. We are making a slight modification of this engine. We are increasing the nozzle length because the engine will have to start and operate at altitude. We do not expect this to be a serious problem. In fact, we would expect to have an engine of this type operating and ready for delivery by late fall of this year. Where we want to do very advanced missions, such as sending some payload toward one of the nearer planets, we would employ a third stage. This stage would contain storable propellants, because we might have to keep some of the propellants for a long time during a trip to a planet, and then reignite the engine. This stage is presently under development by the Jet Propulsion Laboratory.

METHOD OF LAUNCHING VEGA INTO ORBIT

This chart shows the technique whereby a two-stage Vega would get into a 300-nautical-mile orbit. Here we have done something different than in the existing vehicles. We have a restart capability. At the launching site, the booster fires and burns to the first point. The operation through the first two segments here is the standard Atlas-type of operation. The two large engines at the base of the Atlas are dropped, and the Atlas sustainer with a single engine continues to burn. Then the first stage shuts off, and the vehicle coasts to a point that is about a hundred miles above the earth. Then the Vega or second stage is fired for the first time. It is necessary to fire here in order to attain orbital velocity. This firing uses part of the second-stage fuel. Having achieved an increase in velocity the vehicle coasts to the 300-mile orbit. If we did nothing at this 300-mile point, the vehicle would return to a 100-mile perigee. But we want to get a nearly circular orbit at 300 miles. Hence, we apply a further impulse by means of a second firing of the Vega stage.

The engine is being designed to be restartable at altitude. This is the technique that would be employed, for instance, in putting up a large meteorological satellite of about 5,000 pounds weight, one that could continuously observe weather over a period of 6 months to a year. It would have enough equipment to transmit extensive information to many stations on the Earth.

Another application of Vega would occur if the final orbit were at 19,000 miles altitude, where we would obtain a 24-hour orbit. Then the time for one orbit is the same as the time for the Earth to rotate once. The satellite would stay over one place on the Earth, and could be used as a communication relay station.

USES OF VEGA

I have shown on the remaining charts some more advanced missions of Vega, things which we hope to do after the vehicle was proven. Vega will be one of the first vehicles capable of an extensive survey of the Moon's surface. The final Vega stage would be placed in orbit around the Moon. With a television camera in the payload, we would take pictures of the Moon's surface and transmit the information to a receiving station on the Earth.

Another application of Vega is the planet probe. To send something toward a planet with sufficient guidance capability and sufficient instrumentation to transmit information to the Earth, we need at least a thousand pounds of payload. Vega is the first vehicle of our series that has such payload-carrying capability. It is shown here, in an artist's conception, in the vicinity of Mars, which is viewed from its outer moon Deimos.

Finally, there is one more important use of Vega. That is as a successor to the present booster for Project Mercury, the man-in-space project. Vega will be able to put sufficient payload into a low orbit around the Earth for two men in a capsule, to sustain them for perhaps a week or two, enabling them to make many observations in space and perform scientific work.

In summary, Vega is the first general-purpose vehicle of our series. We have scheduled first firings of this vehicle in the latter part of 1960.

PROJECT VEGA

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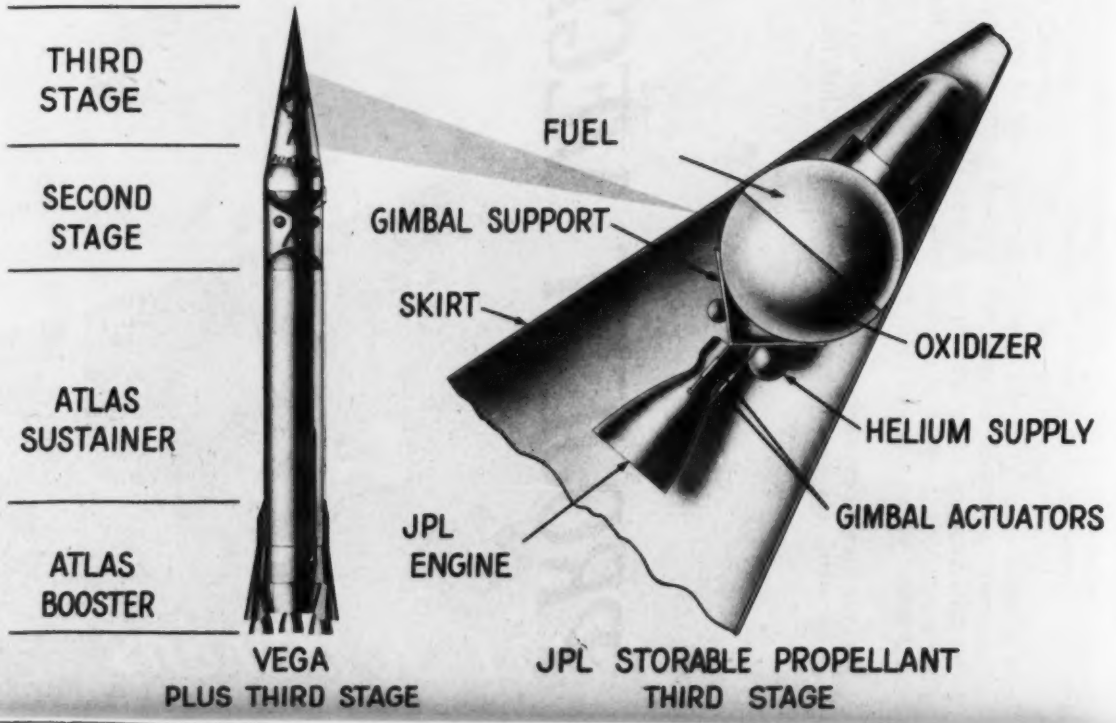
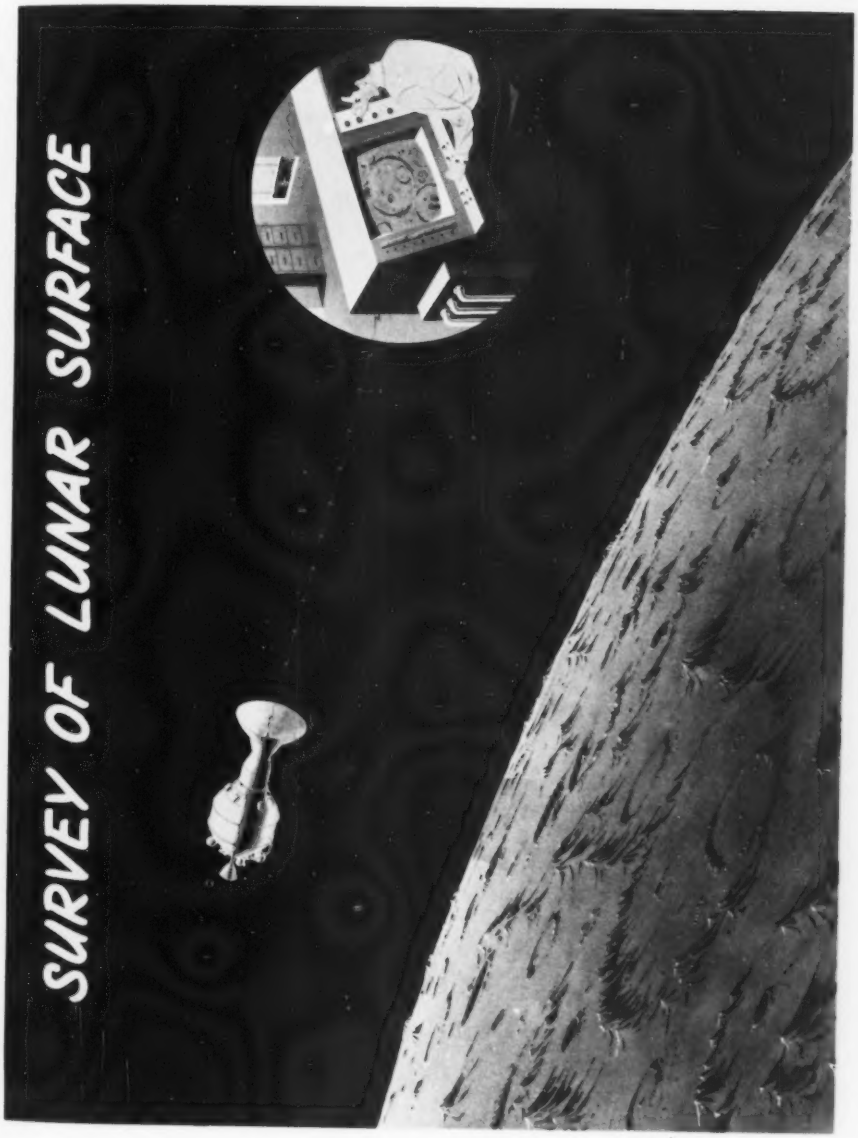
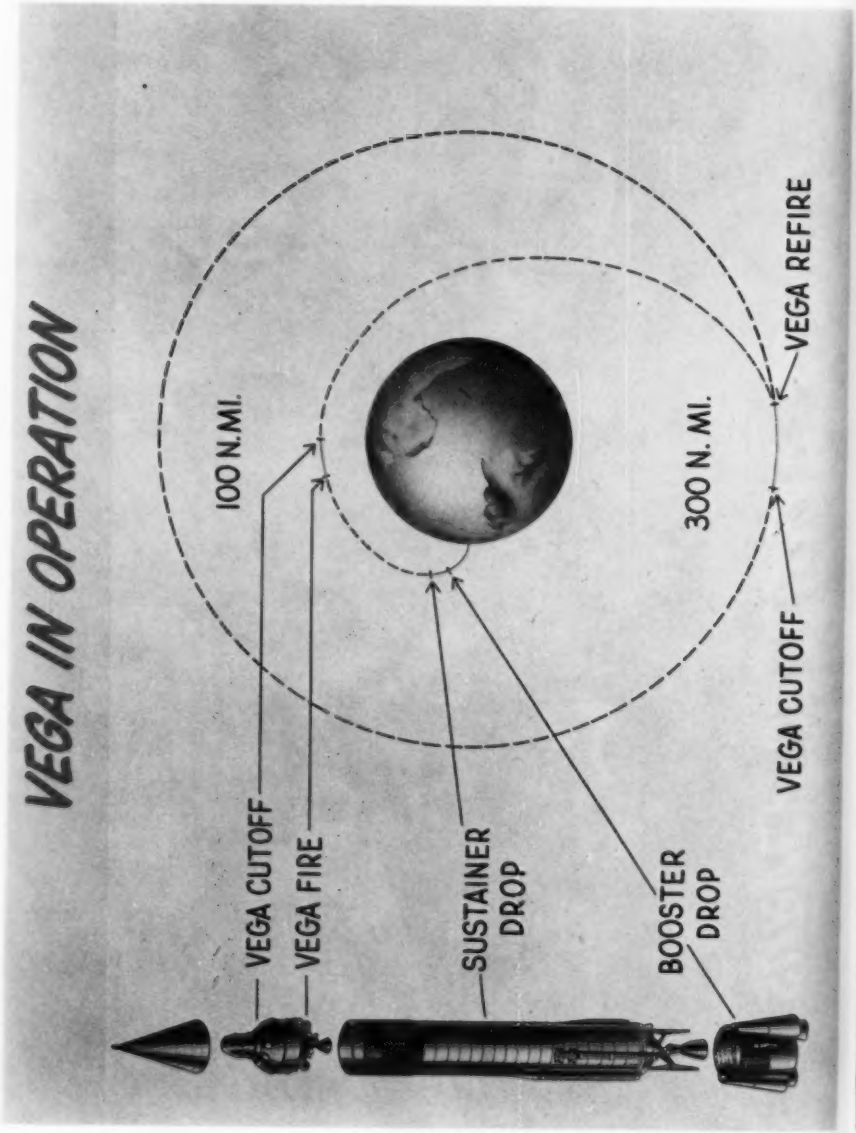
VEGA 3RD STAGE



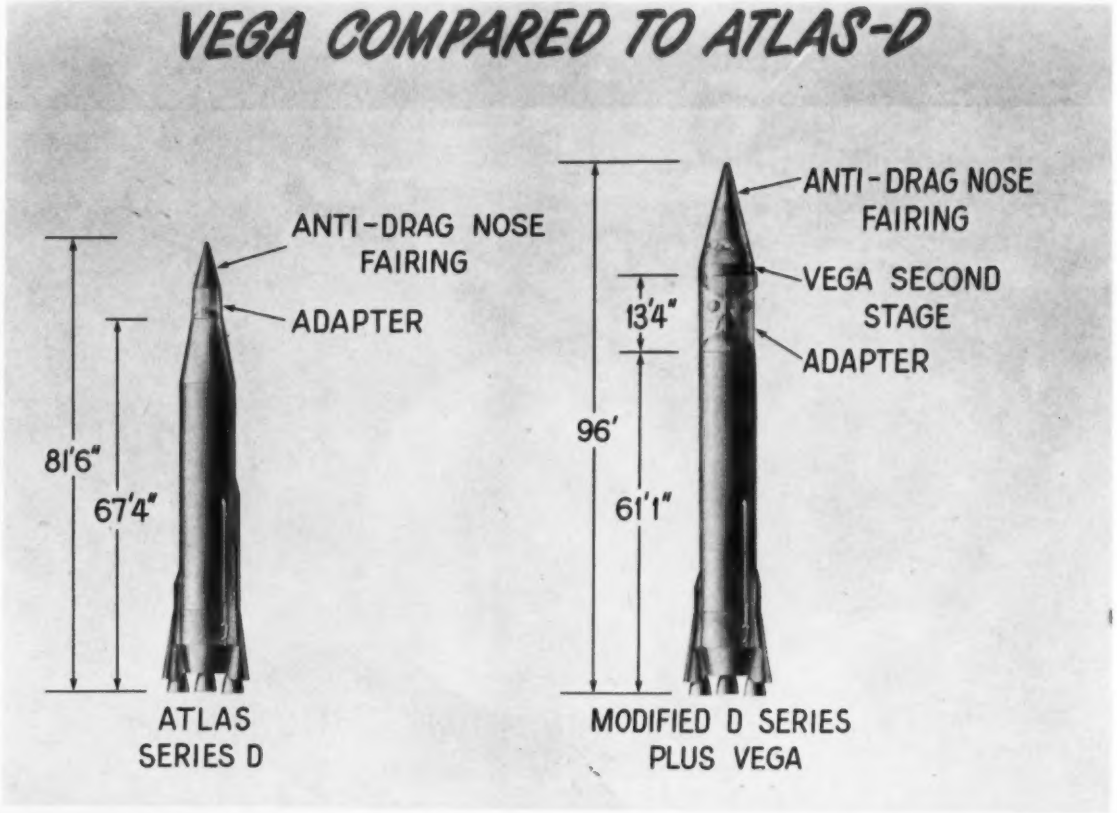


VEGA
PLUS THIRD STAGE

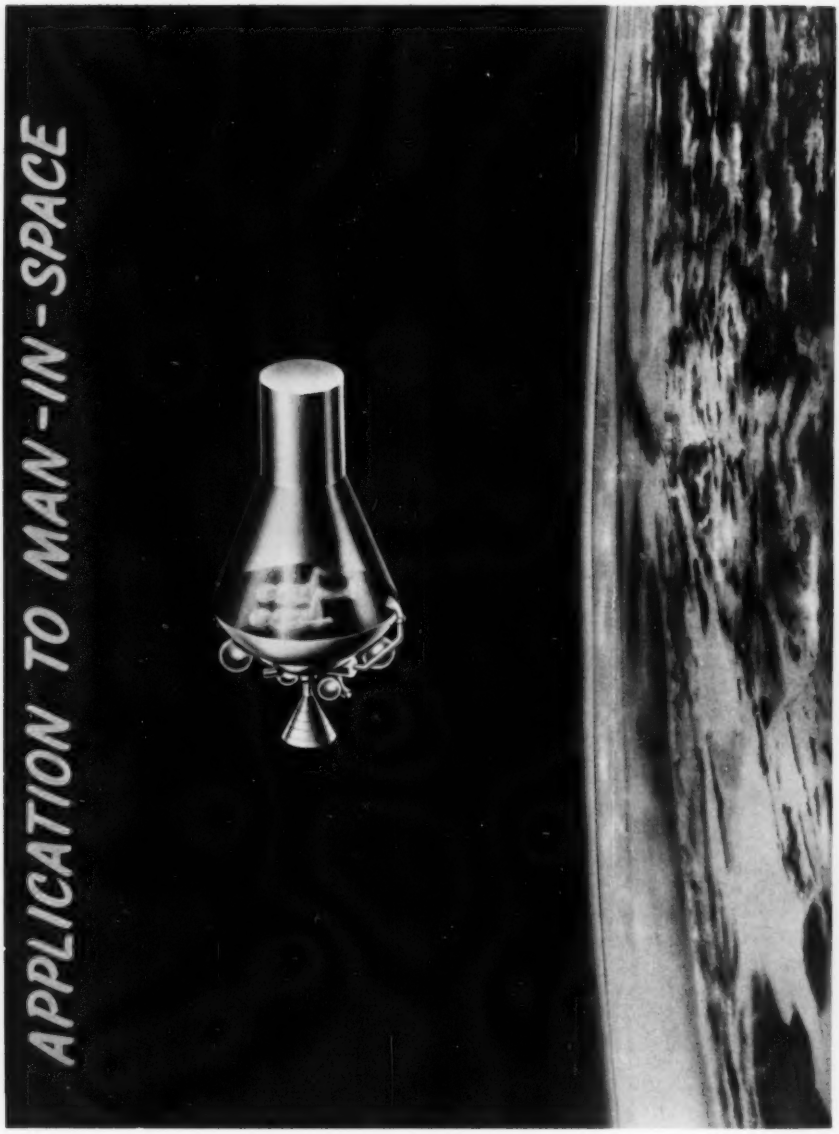
JPL STORABLE PROPELLANT
THIRD STAGE

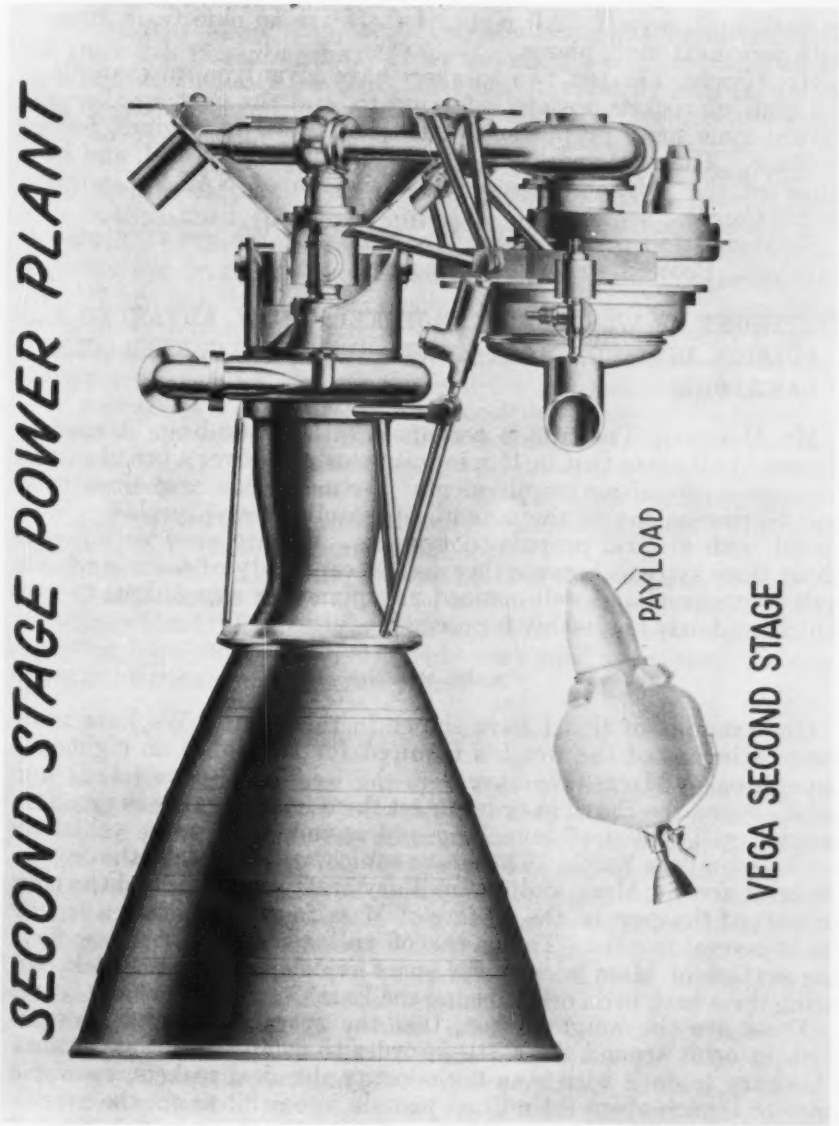

VEGA IN OPERATION
100 N.MI.
300 N. MI.
VEGA CUTOFF
VEGA FIRE
SUSTAINER DROP
BOOSTER DROP
VEGA CUTOFF
VEGA REFIRE

MARS PROBE MISSION


VEGA COMPARED TO ATLAS-D
ANTI-DRAG NOSE FAIRING
ADAPTER
81'6"
67'4"
ATLAS SERIES D
ANTI-DRAG NOSE FAIRING
VEGA SECOND STAGE
ADAPTER
13'4"
96'
61'1"
MODIFIED D SERIES PLUS VEGA

(NATIONAL SPACE VEHICLE PROGRAM)


APPLICATION TO MAN-IN-SPACE


SECOND STAGE POWER PLANT
PAYLOAD
VEGA SECOND STAGE

Senator STENNIS. Members of the committee, since we see how this is running now, would the committee rather ask a few brief questions before this piles up too much, or take another presentation and then ask some questions? I am making notes here, and I think I can go back to it, myself. All right, if there are no objections, proceed with your next man, please.

Mr. HYATT. The last two speakers have given you an example of the kind of rockets we are referring to, and the next speaker will discuss some space propulsion requirements, that is, engines, for use in space. The next speaker is Mr. Wolfgang E. Moeckel, and he is Chief of the Advanced Propulsion Division of NASA Lewis Research Center.

Senator STENNIS. All right, Mr. Moeckel. We are very glad to have you. Proceed, sir, in your own way.

TESTIMONY OF WOLFGANG E. MOECKEL, CHIEF, ADVANCED PROPULSION DIVISION, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO

Mr. MOECKEL. The title is perhaps a little misleading. I am sure we would all agree that in 15 minutes we cannot cover a broad subject like space propulsion requirements. Actually, our next three talks will be discussions on the potentialities and research problems associated with electric propulsion systems. We are very enthusiastic about these systems because they have a capability of reducing fairly well provisioned and well-manned interplanetary expeditions to sizes which are fairly reasonably for use in the future.

MARS MISSION

One example of this I have shown in this chart. We have made some estimates of the weights required for launching an eight-man expedition to Mars. We have here the weight we have to put into orbit around the Earth in order to get these missions underway. This mission will consist of launching and assembling a space vehicle in orbit around the Earth. This space vehicle will then take the crew to an orbit around Mars, and an auxiliary craft will then land the crew or part of the crew on the surface of Mars for an exploration lasting up to several months. Then a takeoff rocket will take the crew from the surface of Mars back to the space vehicle, and that vehicle will bring them back to an orbit around the Earth.

These are the weights, then, that the space vehicle has to start with in orbit around the earth in order to complete this expedition. If we try to do it with even high-energy chemical rockets, we would have to launch about 2.4 million pounds into orbit to get the expedition started. Of this, only about 200,000 pounds is initial payload weight. The rest is nearly all propellant.

NONCHEMICAL PROPULSION SYSTEMS

If we consider the nonchemical propulsion systems; namely, nuclear rockets (which will be discussed later) and electric rockets (which we are going to discuss now), we find that we might be able to do this

entire mission by launching only about 400,000 pounds into orbit, a rather tremendous reduction indeed. This is with the same 200,000-pound payload, but now the powerplant plus propellant weight has been reduced to only about 200,000 pounds.

The right half of the chart shows the launching requirements to get these vehicles into orbit. If we use the 1½-million-pound-thrust booster rockets which are now under development by NASA, we find that to get this chemically powered space vehicle into orbit we would have to launch 100 of these 1½-million-pound boosters. If we launched the nonchemical space vehicle into orbit, this number is reduced to only 16. In addition, if we can cluster four of these, as is now planned, to get a 6-million-pound thrust for boosting from the surface of the earth, we would still require 24 of these tremendous boosters for launching the chemical space vehicle into orbit; only about 4 are required for the nonchemical space vehicle. Assembling these many parts into a single, orbiting vehicle represents a rather tremendous technical problem in rendezvous, and perhaps an even more severe problem is paying for all the boosters required.

If we can go a step further and boost the thrust of the launching rockets to something like 24 million pounds, we find that we could launch the entire nonchemical space vehicle with a single launching; in other words, assemble it on the ground and we would not have to worry about rendezvous and assembly problems in space. This is the potential of the nonchemical system.

I do not want to give the impression that these electric rockets are useful only for the fairly advanced and high payload missions of the preceding chart. That is the chief justification for developing them, but if we have them we can also make very good use of them for more prosaic missions in the next few years.

ELECTRIC PROPULSION SYSTEMS

The electric rockets are characterized by the fact that they can generate only a very small thrust, but they also can generate that thrust for very long periods of time with very low propellant consumption. This means that electric rockets are ideal for those missions requiring a little bit of thrust for long periods of time. The control of the orientation and orbit of earth satellites is one such application. If the satellite must point in the same direction for long periods of time, and be stabilized on a given orbit, then the electric rockets are ideal for such applications.

For instrumented space probes, chemical rockets are now being developed which will be able to undertake Mars and Venus probe missions with quite reasonable scientific payloads. If we go to electric rockets, though, we find we can carry more payload on these missions for the same initial weight; and as we go closer to the Sun than Venus or farther out than Jupiter, the weight advantage of the electric propulsion method becomes ever greater. The reason electric propulsion has these advantages is that we can eject the propellants out the back end at much higher velocity. The higher the velocity with which we can throw the propellant out backward, the less propellant we need for the same mission capability.

NUCLEAR TURBOELECTRIC SYSTEM

This chart shows some of the principles of the nuclear turboelectric propulsion system. The nuclear reactor is the basic energy source. A pump circulates fluid through a reactor to pick up the heat; the fluid is then vaporized, and the resulting vapor drives the turbine which drives the generator which provides electric power to accelerate the propellant out with very high velocities. The vapor which comes out of the turbine is condensed in quite a large radiator in order to get rid of the waste heat. The condensate then goes back through the reactor to pick up more heat. This complete system is very elaborate, and the only justification for it is that we can get very high jet velocities.

As you will remember, with chemical energy, chemical rockets were limited by the fact that chemical reactions just basically do not have very much energy. With nuclear rockets we are not limited energy-wise, but we are limited by material temperature. We cannot get this propellant up to higher temperatures than the materials of the nuclear rocket will stand.

With the electric rocket we are limited in neither way. We can put in all the energy we want, and we are not limited by material temperature, and the reason is this: If we heat the gas or the propellants by electric means, we find that we can use electric fields and magnetic fields to keep the hot gases away from the wall, thereby avoiding the heat transfer problem or the high temperature problem. If we do have electric power, though, we do not really have to heat the gas very hot, because high temperature is only one way in which we can get very high jet velocities and, therefore, low propellent consumption. If we can ionize the propellants as they come out, that is, strip off an electron and make charged particles of them, then we can accelerate them to almost any speed we want to by putting sufficient voltage on them. Charged particles can be accelerated very easily with sufficiently high voltage. So this seems to solve the problem of getting very high jet velocities.

WEIGHT PROBLEM

The limitation now arises in the weight of all this propulsion system. If this system weighs more than the propellants we save, of course we are no better off than in using chemical rockets. So the idea is to get the propulsion system weight down as low as possible. To do this, we might use other basic energy sources, and Mr. English later will go through some of these. I would like only to say here that this nuclear turboelectric type seems to be the most promising from the standpoint of light weight for very large power output, and using this type, jet velocities of the order of 200,000 miles per hour is what we can get. The chemical rocket yields jet velocities of about 10,000 miles per hour; the nuclear rocket 25,000. The best jet velocity here is around 200,000 miles per hour, a factor of over 8 over the nuclear rocket, and about 20 over the chemical rocket.

So we can save a large amount of propellant, and it turns out that the weight estimate we have made of the rest of the propulsion system indicates that overall this will weigh much less than the chemical

rocket, and moderately less than the nuclear rocket for the same mission Due to the high weight, though, of the electric propulsion system; that is, the powerplant required to generate the electric power, we find that we cannot develop much thrust. We get a low thrust which is much lower than the weight of all the equipment. That means the electric propulsion will never be used to launch anything off the ground, because it cannot lift its own weight. So it is strictly a space propulsion system, and has to be launched into orbit, and from there it can undertake the space missions to the other planets.

SPACE MISSIONS

Due to this low thrust, it turns out that the trajectories or paths in space followed using electric propulsion are quite a bit different from those used in high-thrust rockets such as chemical or nuclear. In the case of the high-thrust rocket we follow a path starting from the earth which looks something like this [indicating], and get out to the orbit of the Moon in about 2 days. An electric rocket starting from an orbit around the Earth spirals very gradually because of its low thrust, and it takes about 50 days to reach the orbit of the Moon. This is using 2 pounds of thrust for each 10,000 pounds of weight, which we find to be reasonable for the weight estimates which were made. So the electric rocket does not look particularly attractive for a man-to-Moon expedition if it is going to take 50 days compared with 2 days for a high-thrust system. However, it might still be very useful for transferring large payloads from the Earth to the Moon if you are not interested in fast times, but you are interested in economy of the operation. If we continue accelerating beyond the orbit of the Moon, we eventually acquire enough energy to leave the orbit of the Earth and go on toward the orbit of Venus or Mars. For the interplanetary trips, the times look quite a bit different. The difference between high-thrust and low-thrust propulsion systems timewise is not as great.

MARS EXPEDITION

The reason is that for both cases, when we leave the Earth we have to follow a fairly long coast path out to the orbit of Mars, and the coast time from the Earth to Mars' orbit is about the same for the two systems, a low-thrust and a high-thrust rocket. Also, once we arrive at Mars we have to wait quite long periods of time before Mars and the Earth are in the right position so that we could come back and catch the Earth when it is at the right place, and again the waiting times are about the same for the two systems. So the overall time for the whole roundtrip mission is not too much different, 973 days for the high thrust, and about 1,060 for the low thrust. These times are for what we call the most economical paths. They are the ones that permit us to accomplish the mission with the least total weight. Obviously we would like to reduce these times as much as possible, and our preliminary estimates indicate that with electric propulsion we should be able to reduce 1,000 days to about 600 days, with rather moderate increases in the initial weight for the mission.

MARS VEHICLE

The last chart shows the type of electric space vehicle we have been looking at for accomplishing this eight-man Mars expedition. This is the vehicle which would be launched into orbit to start the men on their way to Mars. The overall length is around 600 feet for this configuration. Electric power required is about 12,000 kilowatts. Thrust is only 58 pounds. Here we have the nuclear reactor system with its shielding and propellent tank. This propellant goes through this pipe and is ejected by the electric accelerating apparatus at the back end. This is the turbogenerator which generates the electric power, which is supplied to the accelerator to accelerate the propellant out at large speeds. Here we show the crew cabin, and here is the landing craft on which part of the crew will settle onto Mars for exploration purposes. A weight breakdown of this system is something as follows: For the cabin, which includes all the communication and navigation equipment and the environment controls, as well as the crew, about 50,000 pounds. A subsistence allowance, including food, water, and oxygen of the crew, about 85,000 pounds. Landing craft with exploration equipment, 40,000 A powerplant, which is all this equipment here except the propellant in the tank, weighs about 76,000 pounds, and the propellant about 70,000 pounds. And we have allowed 29,000 pounds of reserves.

So the gross weight of the entire system is about 350,000 pounds, again for the most economical path which gives us the least weight. If we increase this to something like 450,000 pounds, we think that with the ultimate development of the nuclear electric propulsion system, we may be able to reduce the Mars round-trip time to about a year and a half with fairly reasonable total launching weights. You will notice it takes more weight to supply the crew than it does to supply the powerplant in this case. So anything we can do to reduce this would be very advantageous from a weight standpoint.

Our next speaker, then, will discuss the various methods of accelerating the propellant by using electric power. Mr. Childs will discuss that. Then Mr. English will discuss in detail various methods of generating that electric power for that purpose.

SPACE PROPULSION REQUIREMENTS

EARLY ELECTRIC PROPULSION MISSIONS

1. ORIENTATION AND ORBIT CONTROL

A. COMMUNICATIONS SATELLITES

B. ASTRONOMICAL (TELESCOPE) SATELLITES

C. METEOROLOGICAL SATELLITES

2. PROPULSION FOR INSTRUMENTED SPACE PROBES

A. MARS AND VENUS PROBES

B. SOLAR PROXIMITY PROBES

C. FAR SOLAR SYSTEM PROBES

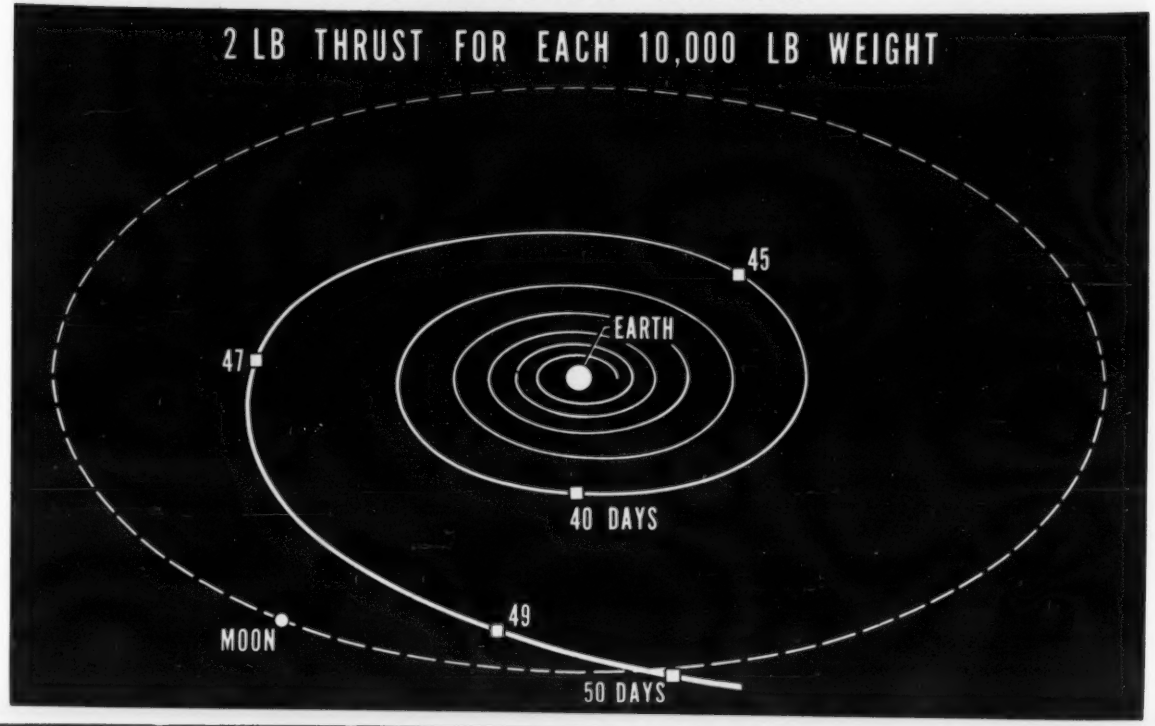
39621 O—59—pt. 1——4

MINIMUM-ENERGY FLIGHT PATH FOR MARS ROUND TRIP

TIME IN DAYS FOR MARS JOURNEY

SYSTEM	ESCAPE FROM EARTH	COAST	DESCENT TO MARS ORBIT	WAIT	TOTAL
$\frac{\text{WEIGHT}}{\text{THRUST}} = 5{,}000$	59	259	31	403	1062
HIGH THRUST ROCKET	—	259	—	455	973

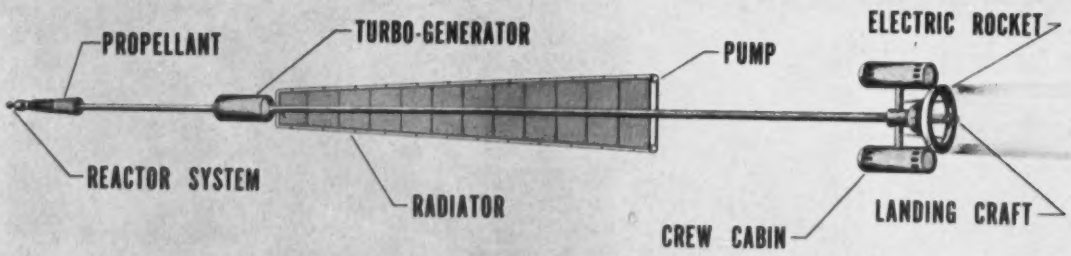
ESCAPE TRAJECTORIES WITH LOW-THRUST PROPULSION SYSTEM



50 DAYS

ELECTRIC SPACE VEHICLE FOR 8-MAN MARS EXPEDITION

LENGTH: 600 FEET **POWER: 12,600 KW** **THRUST: 58 LBS**

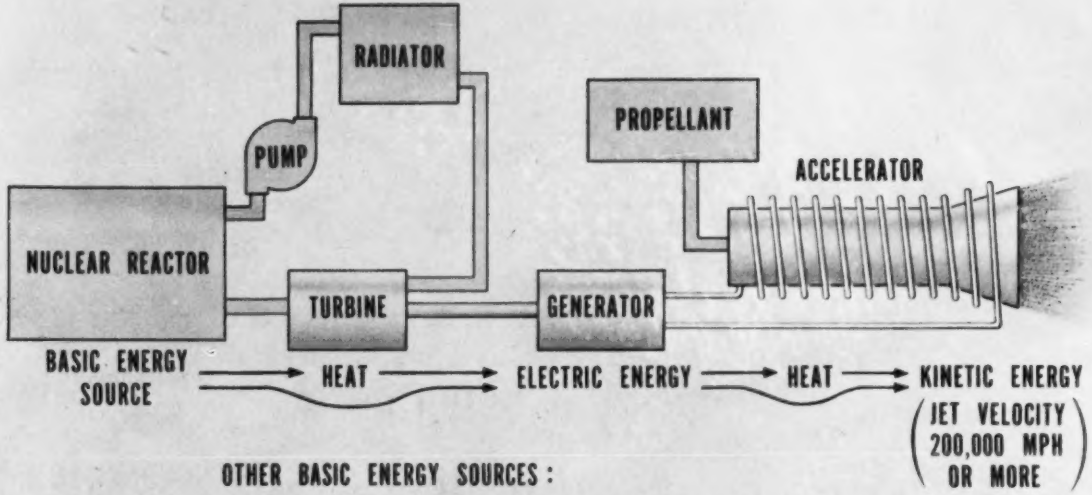


CABIN	50,000 LBS	POWERPLANT	70,000 LBS
SUBSISTENCE	85,000 LBS	PROPELLANT	76,000 LBS
LANDING CRAFT	40,000 LBS	RESERVES	29,000 LBS

GROSS WEIGHT: 350,000 LBS

ELECTRIC ROCKET PROPULSION PRINCIPLES

NUCLEAR TURBO-ELECTRIC TYPE

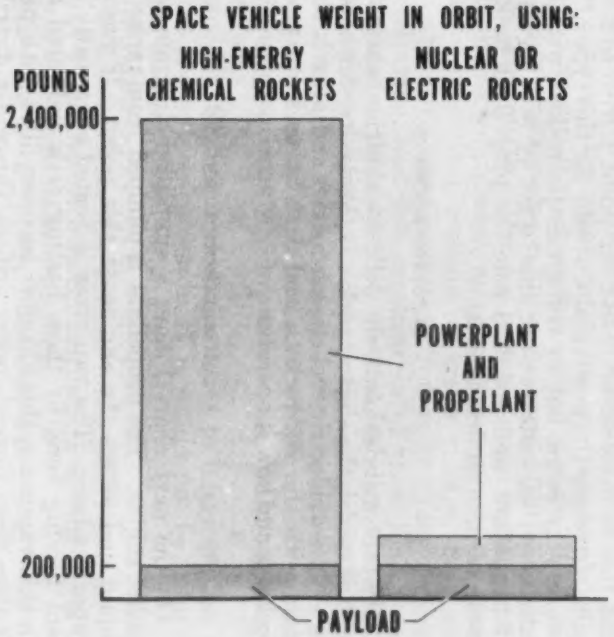


OTHER BASIC ENERGY SOURCES :

SOLAR COLLECTOR (HALF SILVERED BALLOON)
SOLAR BATTERIES
NUCLEAR THERMOELECTRIC
RADIOISOTOPES (POWER DECAYS WITH TIME)

RADIOISOTOPES (POWER DECAYS WITH TIME)

REQUIREMENTS FOR LAUNCHING 8-MAN EXPEDITION TO MARS



LAUNCH ROCKET THRUST MILLIONS OF LBS	NUMBER OF LAUNCHINGS TO ASSEMBLE	
	CHEMICAL SPACE VEHICLE	NON-CHEMICAL SPACE VEHICLE
1.5	100	16
6	24	4
24	6	1
NUCLEAR: 6	6	1

Senator STENNIS. All right. Whom do you have next, Mr. Hyatt?

Mr. HYATT. The next witness is Mr. J. Howard Childs, Chief of the Electric Propulsion Branch of NASA.

Senator STENNIS. All right, Mr. Childs.

TESTIMONY OF J. HOWARD CHILDS, CHIEF, ELECTRIC PROPULSION BRANCH, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO

Mr. CHILDS. Mr. Chairman and gentlemen, the reason for the current great interest in electric rockets was just spelled out by Mr. Moeckel. We are interested in them because they can produce extremely high values of exhaust jet velocity. This means, then, we get more thrust from each pound of propellant that we eject out the back of our engines. This in turn means that we need carry less propellant on board the spacecraft for any given mission. Mr. Moeckel discussed this model of a spacecraft designed for carrying an eight-man crew on a round trip mission to Mars, and he pointed out that the bulk of what we see here is electric power generating equipment. The nuclear reactor here and its shielding, the turbine and the electric generator which are located in this compartment, and the large radiator shown here, are all necessary parts of the electric power-generating plant. As he mentioned, a later speaker is going to discuss this in more detail. But the point I wish to make here is that quite obviously the powerplant weight for this type of propulsion system is very large, but by using electric rockets with their very high exhaust jet velocities we are able to get by with a very small quantity of propellant, and you will note the propellant tank shown here in green is quite modest in size.

ELECTRIC ROCKETS

My talk will deal entirely with the electric rockets themselves; and on this model, the electric rocket is the device shown here. There are two types of electric rockets, ion rockets and plasma rockets. We will start with the ion rockets, and first let us see exactly what an ion rocket is and how it operates.

ION ELECTRIC ENGINE

On the next chart I have a simplified diagram of a typical ion rocket engine. The propellant is pumped from tanks which store the liquid and enters the engine at this point. It flows first into the vaporizer here. The vaporizer is heated electrically by electric current flowing here, by these heating coils indicated here in orange. In this vaporizer, this chamber becomes filled with propellent vapor. It then flows through many orifices, through a distributor plate, so-called because it is designed to evenly distribute this vapor onto the ionization grids located here. These ionization grids must operate at a high temperature, so they, too, are heated electrically; and furthermore, they must be made of some material which has a higher affinity for electrons than does the propellant itself. One combination which therefore shows a lot of promise is cesium, metallic cesium, as the propellant, because it has a low affinity for electrons, and tungsten

as the metal from which the ionization grids are fabricated because it has a high affinity for electrons. Using those combinations, then, each time an atom of cesium comes in contact with these heated tungsten grids, it means one electron leaves the cesium atom and falls into the tungsten metal. When this happens, when the cesium atom loses one of its electrons, it means it has a positive charge and is, by definition, then an ion, so that flowing away from these ionization tungsten grids is a stream of positively charged cesium ions.

Now, we connect the ionization grids and the engine housing around them to the positive terminal of the electric generator, the device shown here. As you know, an electric generator is nothing more than a mechanical device for accomplishing the same thing as does the automobile battery that you use in your car. In other words, it produces a voltage and causes an electric current to flow. In the particular example we are showing here, this generator is capable of producing 40,000 volts, so these metal parts, the ionization grids and the engine housing around them, are operating at 40,000 volts.

Since these metal parts are at such a high voltage, and since the cesium ions are also positively charged, it means that those ions are repelled away from these metal parts by a so-called electrostatic force. In other words, the ions are pushed in this direction [indicating]. And as the ions move downstream through the engine, they enter regions in the engine where the voltage is progressively lower. You will note we have the metal parts of the engine here connected to the generator in such a way that they operate at 20,000 volts. Here we have the metal parts 10,000 volts, 5,000 volts here, 2,000 volts, and finally at the very back of the engine we have the metal parts operating at zero volts or, if you prefer, at ground potential. As these positive ions move into these regions of lower voltage, they are acted on all the while by these electrostatic forces, and they accelerate as they travel along, and this acceleration of these ions, these charged particles, under the action of these electrostatic forces, is exactly the same as the acceleration an object experiences when it falls under the action of gravity. So, by the time our ions have fallen to the back of the engine, they have attained a very high velocity, and it is this high velocity jet of ions which produces the thrust necessary to propel a spacecraft.

Senator YOUNG. Mr. Chairman, I do not want to interrupt, but I am wondering, as the witness proceeds, if it would not be helpful if he would define ions and other terms like that for us.

Mr. CHILDS. All right.

Senator YOUNG. I would be helped if the witness would do that.

Senator DODD. I think we all would like that. I do not think it helps us much unless we have this information.

Senator STENNIS. We are all pretty much lost without it.

Mr. CHILDS. All right. These ions I am referring to could conceivably be any material which has been treated in such a way as to cause it to lose electrons from the material, which leaves each of the particles, these things that were molecules but are now charged particles, leaves each of the particles with a net electrical charge.

Senator STENNIS. And that gives you energy; is that right?

Mr. CHILDS. The fact that they are charged means that you can act on them with electrostatic fields and with electromagnetic fields, and accelerate them electrically.

Senator STENNIS. And that gives them enough thrust to keep them flowing; is that correct?

ADVANTAGES OF ION PROPULSION SYSTEM

Mr. CHILDS. Yes. That is the idea. We want to accomplish the same acceleration electrically, because that is the only way we can obtain the extremely high velocities that we are interested in in this type propulsion system. Conventional chemical rockets and even nuclear rockets simply heat up a gas to a very high temperature, and then expand that hot gas. But here we have a different principle of acceleration. We have charged particles; each of the particles has an electrical charge on them so they can be accelerated by these electric vehicles, and we get higher velocities.

Now, negatively charged electrons that were given off back at these ionization grids where the positively charged ions were created, flow away through the external wiring indicated by the red arrows here. This flow of electrons through the external wiring is exactly the same kind of electric current which you have flowing through the wires of this building to give us lights here. The electric generator is necessary to force the electrons to flow in this direction from the region where the voltage is high to this region at the back of the engine where the voltage is low. The generator acts like an electron pump. It does the work of pumping these electrons through the wires in exactly the same way a conventional pump does the work of forcing liquids uphill through pipes, and so forth.

I will not go into the details of this electron gun here except to say it is a device for accelerating these electrons outward in a jet or beam, if you prefer, using electrostatic forces in exactly the same way that these ions were accelerated out using electrostatic forces, so here we have a beam of ions, and here we have a beam of ions that is directed into the ion beam in such a way that the electrons will mix with the ions and eventually neutralize their charge. The ions are charged positively and the electrons negatively, so when they get here the overall charge will be neutral, or zero.

The electrons are such lightweight particles that they do not contribute any appreciable amount to the thrust, but it is nevertheless important that we eject them in this manner, because if we did not do that, if we simply ejected the positively charged ions and retained the negative electrons on board the space vehicle, then quite obviously it would build up a tremendous negative electrical charge, and we would then have a negatively charged spacecraft and a cloud of positive ions in space behind the vehicle, and there would then be an electrostatic force of attraction between these positively charged ions and the negatively charged space vehicle which would slow the space vehicle down. So by ejecting the electrons in this way, we can prevent this from happening.

NASA ION PROPULSION RESEARCH

The NASA is conducting research on each of the components of this type engine. In one of our laboratories we are investigating the vaporization of various propellant materials, and we are studying the flow rates of these propellants through orifices of the type that you

would use in this distributor plate here. In another apparatus we are studying the effectiveness of heated tungsten and other materials in converting propellants into ions. In addition to the work with cesium as propellants, we are also looking around trying to find other materials which would make suitable propellants for an ion rocket. We are also examining other types of ion sources which differ rather markedly from the one illustrated here. These include the electric arcs and certain types of high frequency electrical discharges in gases. These things are known to produce some ionization. We are also conducting research on various ion accelerator configurations to determine which configurations will most efficiently accelerate these ions to the necessary high velocity with a minimum of ion impingement on the metal parts. This, of course, is quite important, because any impact of those high-velocity ions on the metal will cause severe erosion of the metal and will greatly reduce the operating life of the engine. Finally, we are doing research with electron guns to determine which configurations will best eject these electrons and promote mixing between the electrons and the ions.

As we determine the necessary design principles from this research with the various engine components, we make use of these data to design and build small-scale ion rocket engines which can then be tested in some rather elaborate large vacuum tank facilities which are presently being installed at the Lewis Laboratory. The first of these large vacuum tanks has been in operation since the middle of January.

One of the engines we are building to test in this first tank is shown in this next chart. This engine has in it all the same operating principles, all the same components, as were in the simplified diagram I have just described, only here where we deal with a practical engine, it becomes necessary to locate many of these parts very close together so the whole thing becomes very compact, as you can see. I think you will be able to recognize the propellants vaporizer here; the distributor plate which is shown here in orange. It is the plate with all the holes in it. It is the same as the distributor plate I talked about on the preceding chart. The tungsten ionization grids are shown here in yellow. The ion accelerator is in blue. And at the back of the engine we have six electron guns arranged in a hexagonal pattern around the periphery of the ion beam. Each of these electron guns will emit a beam of electrons through a thin slot like the one indicated here.

I have here an actual model of this engine which I will pass around so that you can get a closer view of it, so that you can also see the exact size of the engine. This model is exactly the same size as the engine that we are building, and this engine was designed to produce a tenth of a pound of thrust. This is not enough thrust to be of any interest for a large manned space vehicle. However, it is enough thrust to be of interest on satellites for adjusting the orbit, and for attitude control of the satellite.

We are not alone in this field of research. Several companies are also conducting research on the ion rocket. At the present time no one has yet demonstrated an ion rocket engine which has all the performance features necessary to make it a practical device for space propulsion. The requirements are varied and very stringent, and

include such things as the ability to produce this high-velocity jet of ions and to do it efficiently, that is, with substantially 100 percent efficiency in converting the electric input energy into kinetic energy of the exhaust beam of ions. Then, of course, an engine to be practical must ionize essentially all of the propellant that you feed into the engine, and in addition it must produce a reasonable amount of thrust for a given engine size. With the type of research program which is currently underway in the NASA and in industry, it appears quite probable that we will have small-scale ion rocket engines in operation which have these performance characteristics to at least a reasonable degree, by the time the electric power generating equipment has been developed to the point where test of an overall propulsion system might begin. So much for the ion rocket.

THE PLASMA ROCKET

Now let us turn our attention to the other category of electric rockets; namely, the plasma rocket. The plasma rocket differs from the ion rocket in that here we do not separate the ions and the electrons and eject them in two separate beams. Rather, we leave the ions and electrons intermingled and accelerate them together in a common beam. By definition, plasma is simply a mixture of positive ions and negative electrons. The way you produce a plasma is to take any body of gas, any gaseous material, and heat it up until the temperature is so high that the molecules of the gas dissociate, separate into positive ions and negative electrons. You will have the same number of positively charged particles as you have negatively charged particles in this gas, so the whole mass of gas is still electrically neutral, but microscopically it is made up of these positive charges and negative charges of these different particles. They do not recombine to form molecules, because the temperature of the gas is too high. And that is all that a plasma is. It is a body of ionized gas.

PLASMA ACCELERATION TECHNIQUES

You can accelerate a plasma by various types of electromagnetic forces. One device for accelerating plasma is shown in my next chart, which consists of two copper bars shown here in pink. These are called electrodes, and they are connected to opposite terminals of a high-voltage supply. With this high voltage difference between these two electrodes, a spark will strike between them, and this spark that strikes is exactly the same as the sparks that you see on the spark plugs in an automobile. The spark will form first at this point where the spacing is least between the two electrodes, and at this point we feed the propellant in. It is fed in as a gas through this hollow tube, so the propellant is fed directly into the spark formed across here, and the electric currents flowing through this spark serve to heat up the incoming propellant until it becomes ionized. In other words, it converts it into a plasma. We will then have an electric current flowing across from one of these copper bars to the other, and we have a magnet, as indicated here, arranged so that the magnetic field has this direction, as indicated by the red arrow here. The magnetic field

is at right angles to the direction of flow of the current in this spark.

Now, any time that you have a current traveling at right angles to a magnetic field, you generate a force which is at right angles to both the core and the magnetic field. So this force is parallel to the copper bars, and each of the charged particles in this plasma experiences this force, and they are pushed along the rails so the plasma and the spark that is traveling through the plasma move down the rails. Then they will be at the location indicated here, and they accelerate all the way, and the plasma is then ejected at the end of the rails. When that happens, the electrical circuit is momentarily broken, and the voltage builds up, and a new spark will strike back at this point, and the process is repeated. The end result is then we have a pulsing jet plasma being expelled from the ends of these rails. Now, this device we have diagramed here is a laboratory model of a plasma accelerator. It is not a practical plasma rocket engine yet. It is not large enough and it does not produce enough thrust. And to make it into a practical plasma rocket, we would not use a permanent magnet as indicated here, but rather, an electromagnet. We have been working with this device for some time. We know we do get high-velocity plasma being ejected from it. We get some thrust from it, but we do not yet have the types of instrumentation necessary to determine its exact performance and its efficiency. The necessary instrumentation is now being developed, and we will continue work with this device.

Another type of plasma accelerator is shown on my final chart here. It is entirely different from the one I have just described. Again it is a laboratory model we are working with. It consists of a long glass tube, indicated here. The propellant is fed in as a gas at this point, and around the outside of our glass tube we have several copper coils as indicated here. We supply a high frequency electrical current to these coils, current of the type that is used in radio transmission, so we then have an oscillating current in these external coils. This current creates an oscillating magnetic field in this region inside the tubes, and this causes any ions or electrons, any charged particle that is in the propellant, to oscillate violently, and in so doing they strike incoming molecules of propellant and hit them so hard they heat them up and produce further ionization, and the end result is that all of the incoming propellant is heated until it is ionized and until it becomes a plasma, and all of this happens because of the action of this high frequency current in the external coil. You will recognize this as a form of induction heating. That is exactly what it is. Only in this case we heat this gas up to such a high temperature that it becomes a plasma. This hot plasma then expands and starts to flow down the tube. At the right moment in time when it has arrived underneath this first accelerator coil indicated here, we then send a sudden burst of current through this coil, and this current creates a magnetic field in the region inside the tube as indicated by the dashed lines here, and this will squeeze this plasma and shove it down the tube.

If you gentlemen have ever milked a cow by hand, you know exactly the type of force that this magnetic field exerts.

Senator STENNIS. You are getting into the field of some of us now, if I may just interject here. [Laughter.] Is that your last chart?

Mr. CHILDS. That is my last chart; yes, sir.

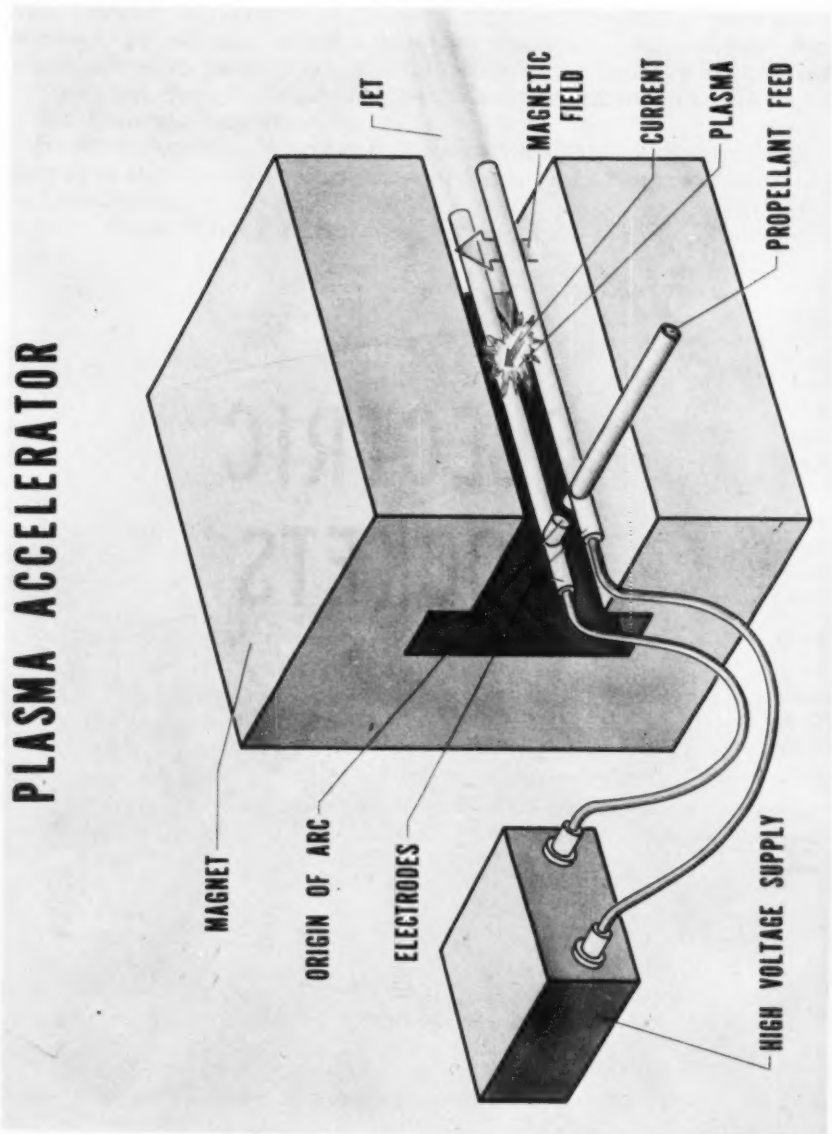
Senator STENNIS. You covered some very fine points—it reminds me of points of physics that I had long since forgotten. Is it a fair summary to say that whereas now you use liquid fuel and solid fuel, you want us to know you are conducting very extensive experiments in electrical energy of various types, whatever you call it?

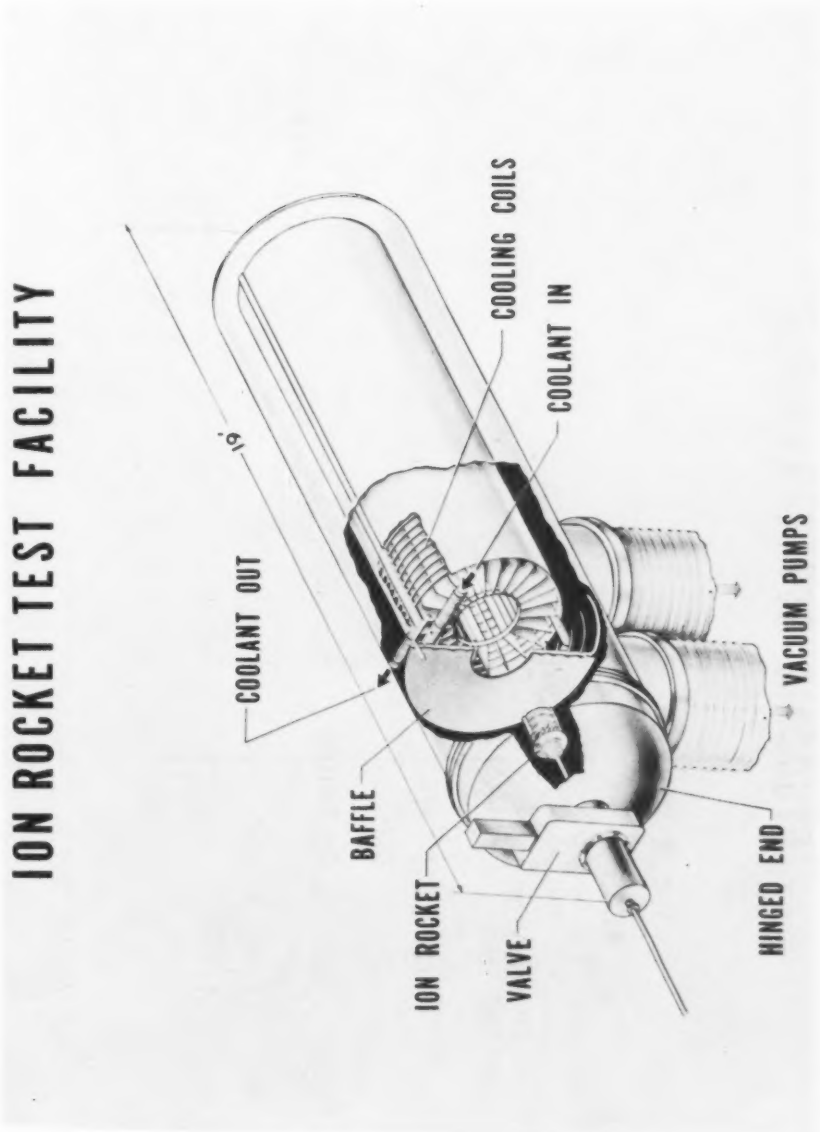
Mr. CHILDS. Yes, sir.

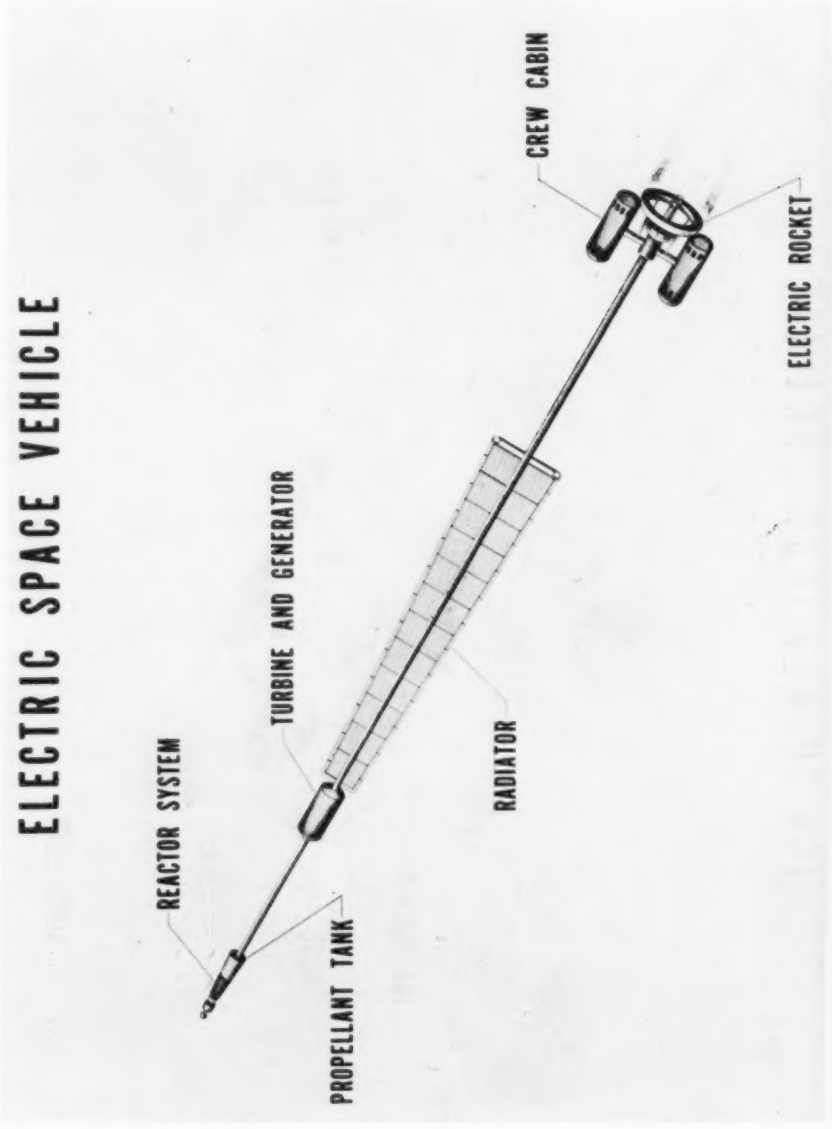
Senator STENNIS. Whether it is the storage battery type or the type that runs through the wires here—you think it has a great possibility, as I understand it.

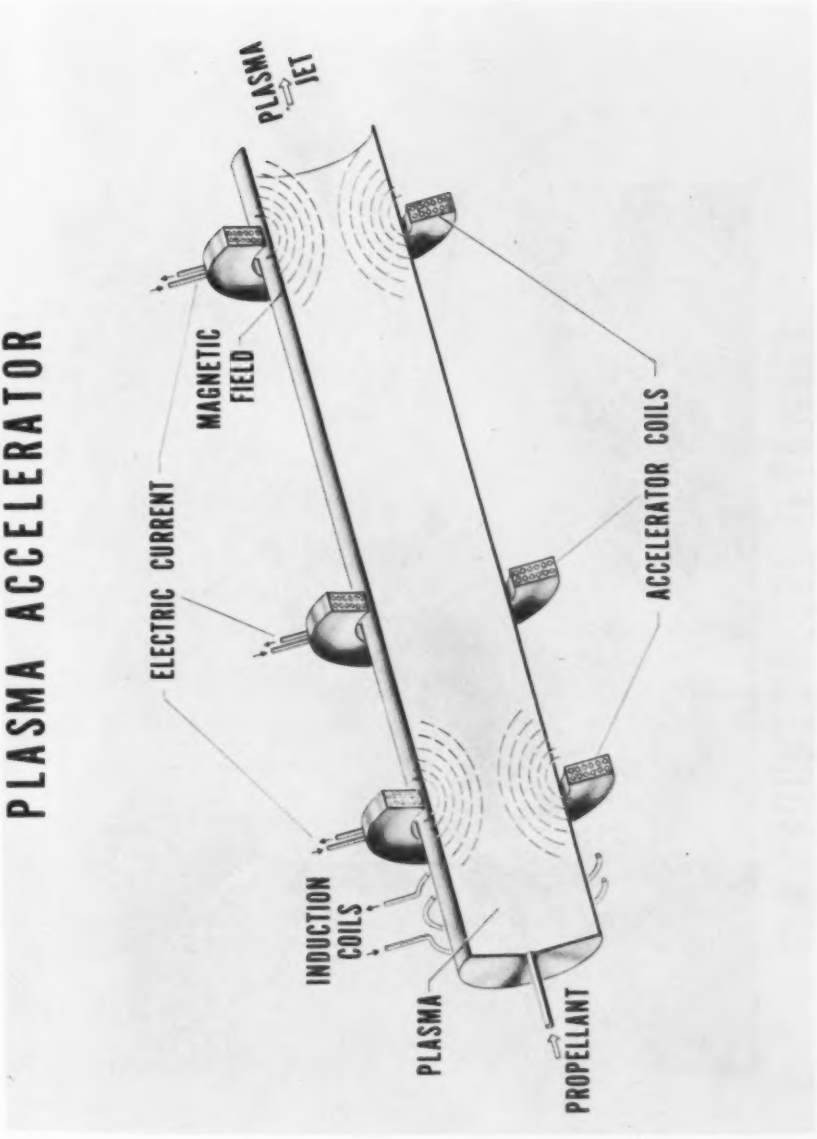
Mr. CHILDS. That is right.

ELECTRIC ROCKETS

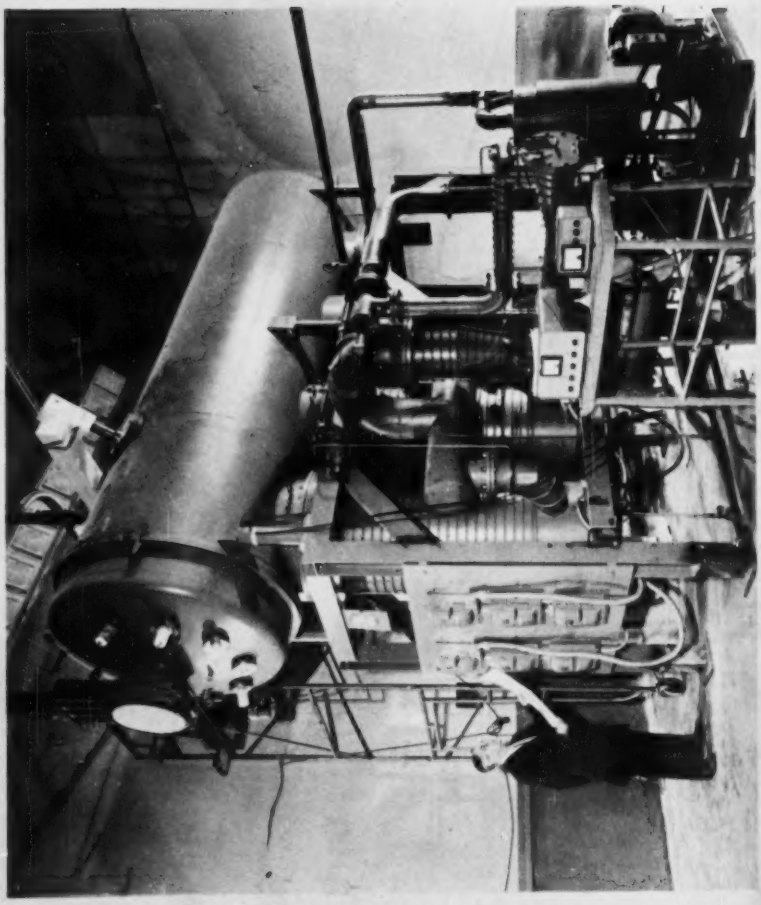

PLASMA ACCELERATOR
JET
MAGNETIC FIELD
CURRENT
PLASMA
PROPELLANT FEED
MAGNET
ORIGIN OF ARC
ELECTRODES
HIGH VOLTAGE SUPPLY

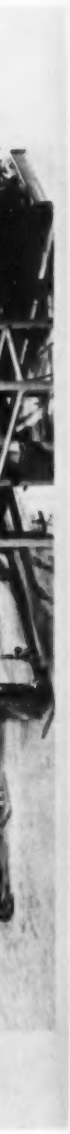

ION ROCKET TEST FACILITY
19'
COOLANT OUT
COOLING COILS
COOLANT IN
BAFFLE
ION ROCKET
VALVE
HINGED END
VACUUM PUMPS

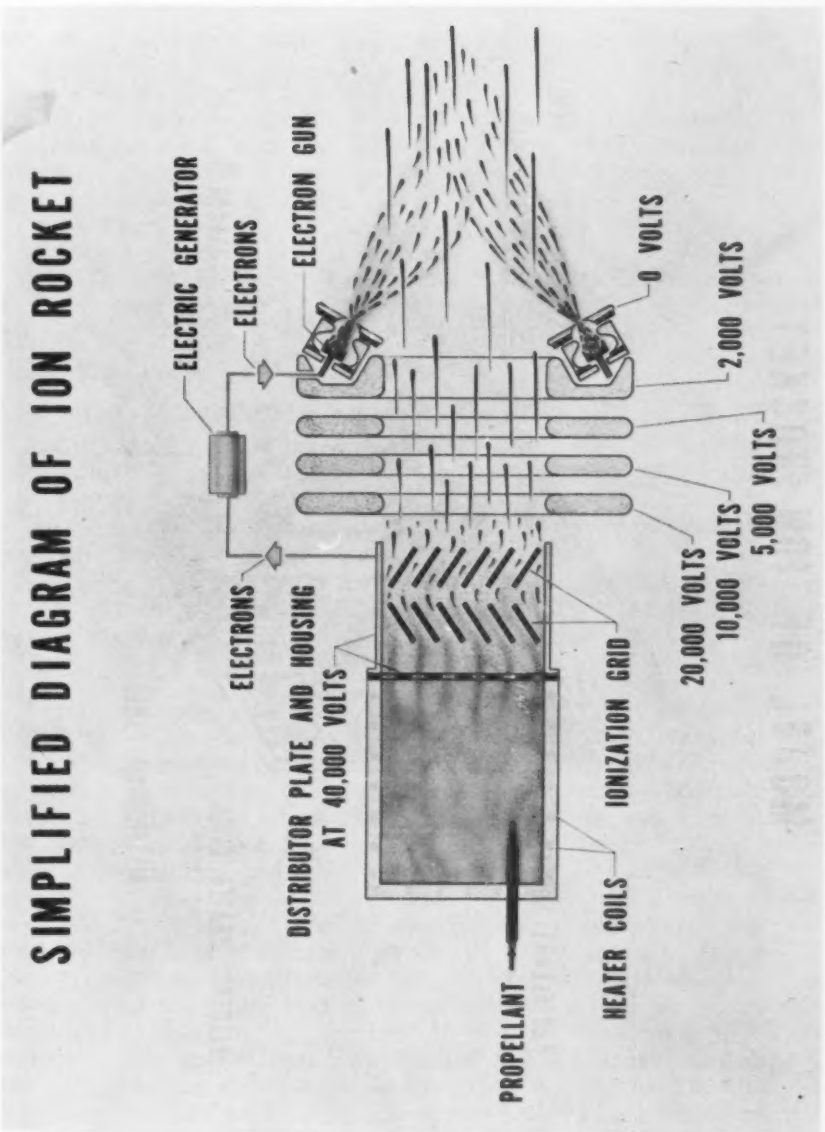

ELECTRIC SPACE VEHICLE
CREW CABIN
ELECTRIC ROCKET
REACTOR SYSTEM
TURBINE AND GENERATOR
RADIATOR
PROPELLANT TANK

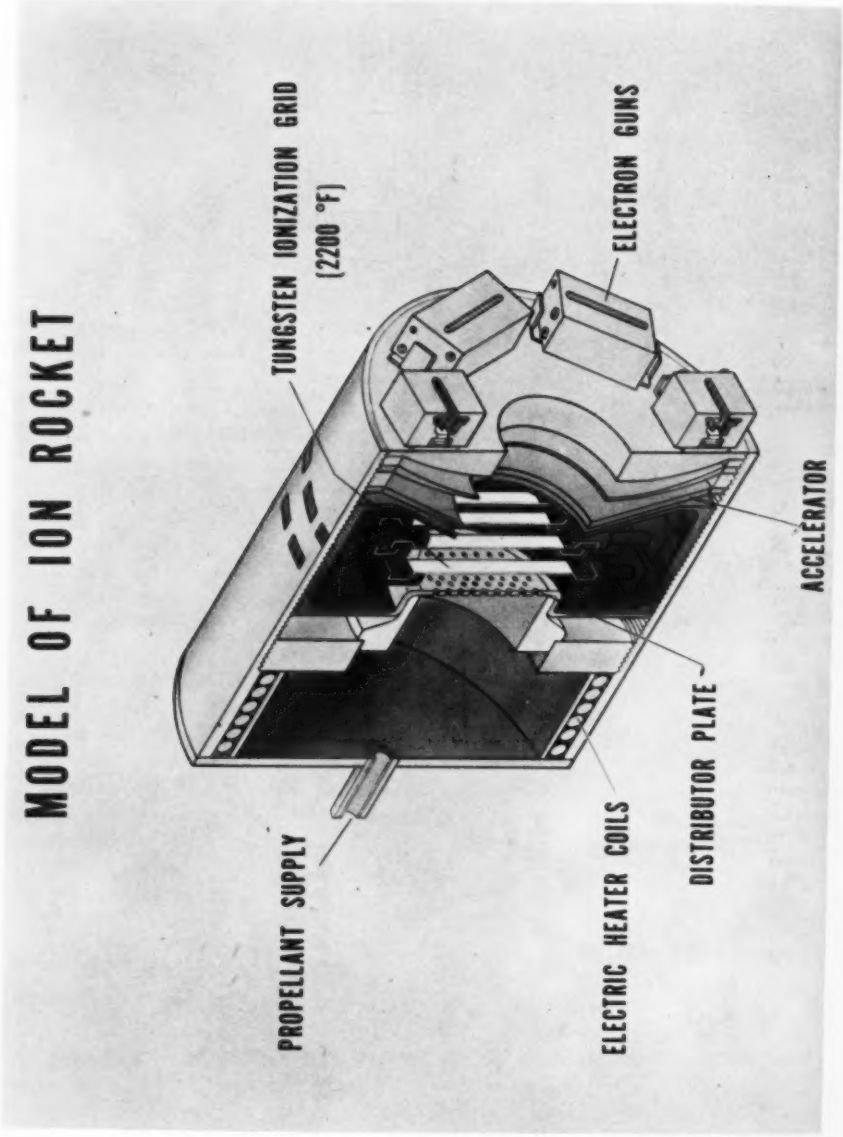

PLASMA ACCELERATOR
PLASMA JET
MAGNETIC FIELD
ELECTRIC CURRENT
ACCELERATOR COILS
INDUCTION COILS
PLASMA
PROPELLANT

ION ROCKET TEST FACILITY






SIMPLIFIED DIAGRAM OF ION ROCKET
ELECTRIC GENERATOR
ELECTRONS
ELECTRON GUN
0 VOLTS
2,000 VOLTS
5,000 VOLTS
10,000 VOLTS
20,000 VOLTS
ELECTRONS
DISTRIBUTOR PLATE AND HOUSING AT 40,000 VOLTS
IONIZATION GRID
HEATER COILS
PROPELLANT


MODEL OF ION ROCKET
TUNGSTEN IONIZATION GRID
(2200 °F)
ELECTRON GUNS
ACCELERATOR
PROPELLANT SUPPLY
ELECTRIC HEATER COILS
DISTRIBUTOR PLATE

Senator STENNIS. I believe you have one other presentation now with reference to this electrical power in space; is that correct?

Mr. HYATT. Yes, sir, Mr. Chairman. This is our most technical discussion.

Senator STENNIS. Yes, sir. We appreciate it very much. I just wanted, while he was there, to be certain we had caught the practical import of it.

Mr. HYATT. Yes, sir.

Senator STENNIS. And that was an expression of appreciation, not criticism—you do want the gentlemen to ask questions. You have one other presentation, and then we would reach a good place, would we not, to have some questions?

Mr. HYATT. Yes, sir.

Senator STENNIS. All right, proceed.

Mr. HYATT. The next witness is Mr. Robert E. English, Associate Chief, Power Production and Shielding Branch, Lewis Research Center.

Senator STENNIS. All right, Mr. English.

TESTIMONY OF ROBERT E. ENGLISH, ASSOCIATE CHIEF, POWER PRODUCTION AND SHIELDING BRANCH, NUCLEAR REACTOR DIVISION, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO

Mr. ENGLISH. Gentlemen, I am going to discuss the electrical power for these electrical systems.

We have three energy sources. We might get this power from chemical, solar sources, we can use energy from the sun, or from various nuclear sources.

CHEMICAL ENERGY

A chemical energy source is familiar to all as a battery for a flashlight. This chart shows you how weights might vary for each kilowatt of energy as a function of time. This lead acid cell is the storage battery used in your car. A silver-zinc cell is a more recently developed type for use in aircraft and missiles. If you wish to use 1 kilowatt of power for 1 day, a lead-acid cell would have to weigh about a thousand pounds. If you wish to do it for 2 days, it will take about 2,000 pounds of lead-acid cell. The important point I wish to make is, if you wish the cell to run for longer periods of time, you must provide a larger battery so it will weigh more, so the weight goes up as the required time goes up. I have shown here a third line representing the limit that chemical systems might be conceivably developed to achieve, not so much to say they are going to be improved to that extent, but I wish to use it for purposes of comparison. Here is this same line from the preceding chart. The reason it is so steep now is that I have changed this scale; where before we used to say 1, 2, 3 days, I now have 100, 200, 300 days, so this line then is very steep.

SOLAR ENERGY

We could use solar energy and solar cells which have already been used in the Vanguard satellite, and they can have a weight such as this. So you can see for very short times the chemical systems can be lighter, but that the solar system soon becomes the lighter system

to employ. One disadvantage of the solar cells is that when they go into the shadow side of the earth or any other astronomical body, the lights go out and the power fails, and it is then necessary to have some other means of providing electric power. The thing we consider for service was that you could have a storage battery, increase the size of the solar batteries over the ones here, charge the solar battery in the sun and discharge it when you are in the shade. This requires raising the weight to something like this [indicating], but even in that event, you see, if you go about 2 months of time, the solar battery is lighter than any chemical system might be. You can use the solar energy in another form. You can use that solar energy to heat a liquid in a boiler, for example, you could boil water, run that steam through a turbine, then condense that steam in this large radiator, and pump the water back into the boiler where it could be reused. This steam would drive a turbine which would power a pump and supply most of its power to this generator for electrical power. This is exactly the principle that the steam powerplants here on the Potomac River use for supplying electrical power to the city of Washington.

In our instance, we have two differences. These powerplants here on the river condense this steam by heating the Potomac River, and unfortunately we do not have such a river in space, so we have to get rid of this heat by radiating it. In other words, this is literally a radiator. It has to be large enough and hot enough so that merely by glowing it can get rid of the heat for condensing the steam. In other words, we cannot use water as this fluid. We plan to use metals. Mercury, for example, is one metal considered. You could boil it here and run it around through this system the same way as the steam. Other metals are rubidium, potassium, and sodium. You need to focus the sunlight on this boiler, and these are some solar- energy collectors which have been built as models by our Langley Laboratory. These solar collectors are very large, as they are planned to be used in space, and so it is necessary to collapse these collectors so that they can be packaged in an economical way for launching into space, and they need to be opened up once they are gotten up there. This is one that operates in the fashion of an umbrella and focuses sunlight on that ball in the center, which would be the boiler for the power system. This is another type that is inflated. This kind of thing will be discussed with you a little more on Thursday when Mr. Heldenfels will talk to you.

NUCLEAR ENERGY

For nuclear energy sources, we have classified them according to radioisotope, fission of uranium or plutonium, or fusion sources. We presently have no program on the application of fusion to the electrical propulsion. The AEC has a program in this area, and we are going to wait until they have advanced this field of effort further before we do anything with it. A characteristic of radioisotopes is that they decay. Radioisotopes are familiar to you. They are radium in a luminous dial of a watch, cobalt 60 used in medical treatment, and strontium 90 which has been in the news considerably lately.

When I say the radioisotopes decay, I mean the power falls with time. This means the device which would employ them would also have a decreasing power output. This can be made more flat by choosing a radioisotope which lasts for a longer period of time, but then you have to pay the price of reduced power output at the beginning of the life of the vehicle. This reaction, this decaying, is something we cannot control. We cannot hasten it. We cannot stop it. This also means that these devices radiate during their preparation for launching, and thus constitute a hazard at that time. This does not mean they cannot be used. Rather, it means we have to take additional precautions in their use during launching.

SNAP III

One device that the Atomic Energy Commission is developing that uses radioisotopes is called Snap III, and that operates in this way. It consists of two kinds of wires. For example, this could be an iron wire; this could be a copper wire, and this could be a copper wire. This junction of the two wires we will heat. This junction we will cool. In this way the electrical energy is produced directly. This is an old principle which has been known for over a hundred years now. From this you can get energy directly. This particular device was in the news in January. I believe they actually had a model here in Washington in January of this year.

SNAP I

Another system would use the energy from the radioisotopes to heat this boiler, and this system is also being developed by the AEC, and has been given a name Snap I.

SNAP II

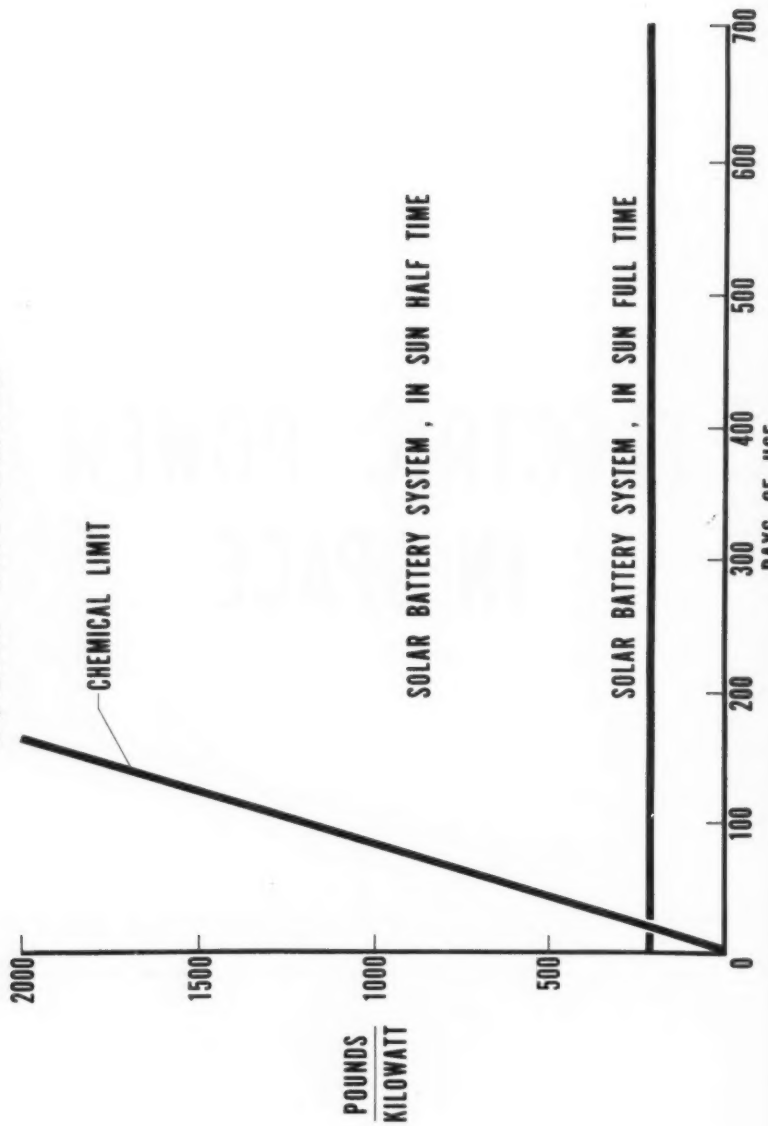
Reactors can also be used to heat this boiler. We can use, say, the fission of uranium to supply heat to boil this fluid, and the Atomic Energy Commission is also developing a system of this kind, and it is called Snap II. We think this program is a very good one, and we think this particular kind of device, a reactor in combination with this turboelectric system is the most promising device for producing large amounts of power, particularly for propulsion. We have asked the AEC to develop a system about 10 times as large as Snap II, and they are cooperating with us in the development of this system. One thing we need in these systems is high temperatures. The radiator for these systems, the largest single device, is the most vulnerable to damage by meteors traveling through space, and I show here what these weights might be. If that radiator is at 700° F., it will then be over half of the total weight of a large system. The power unit, by this I mean the boiler, the turbine, generator, the pumps, the pipes, all these other things have this much—the shielding for the reactor would weigh something like that, and the reactor would weight this much. If we can raise the temperatures at which these systems operate we can then cut the radiator down to a value such as this comparable to the other components. We thus seek to operate them at higher temperatures.

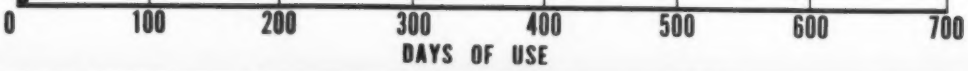
By way of summary, these are the points I wish to make: The chemical systems are useful for short times. For longer times they become far too heavy. Solar systems are useful over a wide range of powers. Energy collection is the main problem. Nuclear systems, especially in combination with the turboelectric systems, we think, are currently the most promising type for current intensive development.

Senator STENNIS. Did you say the nuclear?

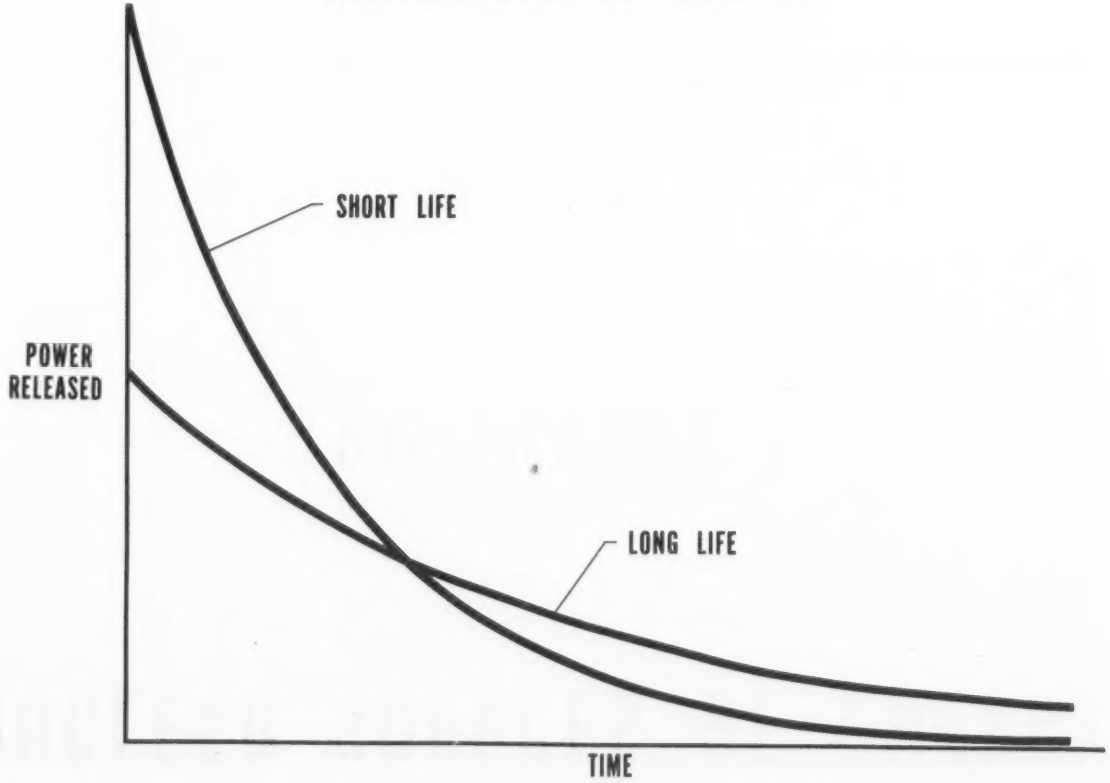
Mr. ENGLISH. We think the nuclear turboelectric system is the best type for long-range development.

ELECTRIC POWER IN SPACE


SOLAR BATTERIES
CHEMICAL LIMIT
SOLAR BATTERY SYSTEM, IN SUN HALF TIME
SOLAR BATTERY SYSTEM, IN SUN FULL TIME
POUNDS / KILOWATT
2000
1500
1000
500
0
100
200
300
400
500
600
700
DAYS OF USE



RADIOISOTOPES DECAY



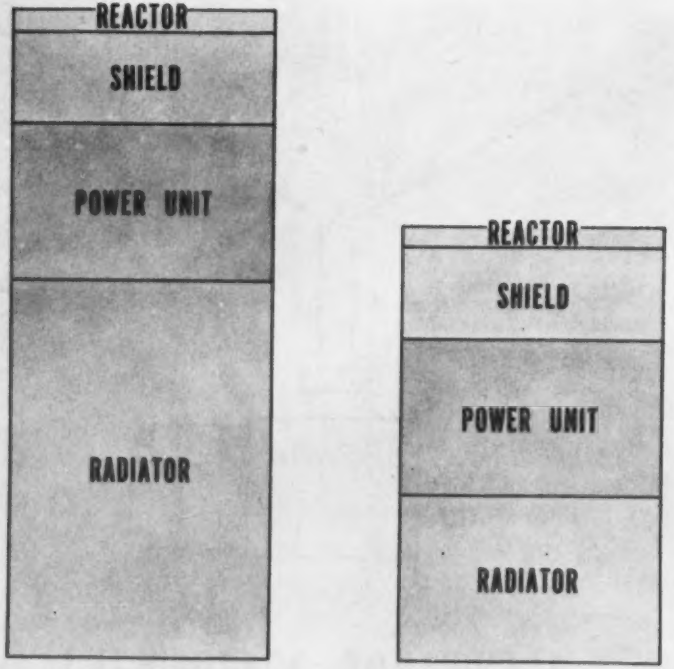
NUCLEAR SOURCES OF ENERGY

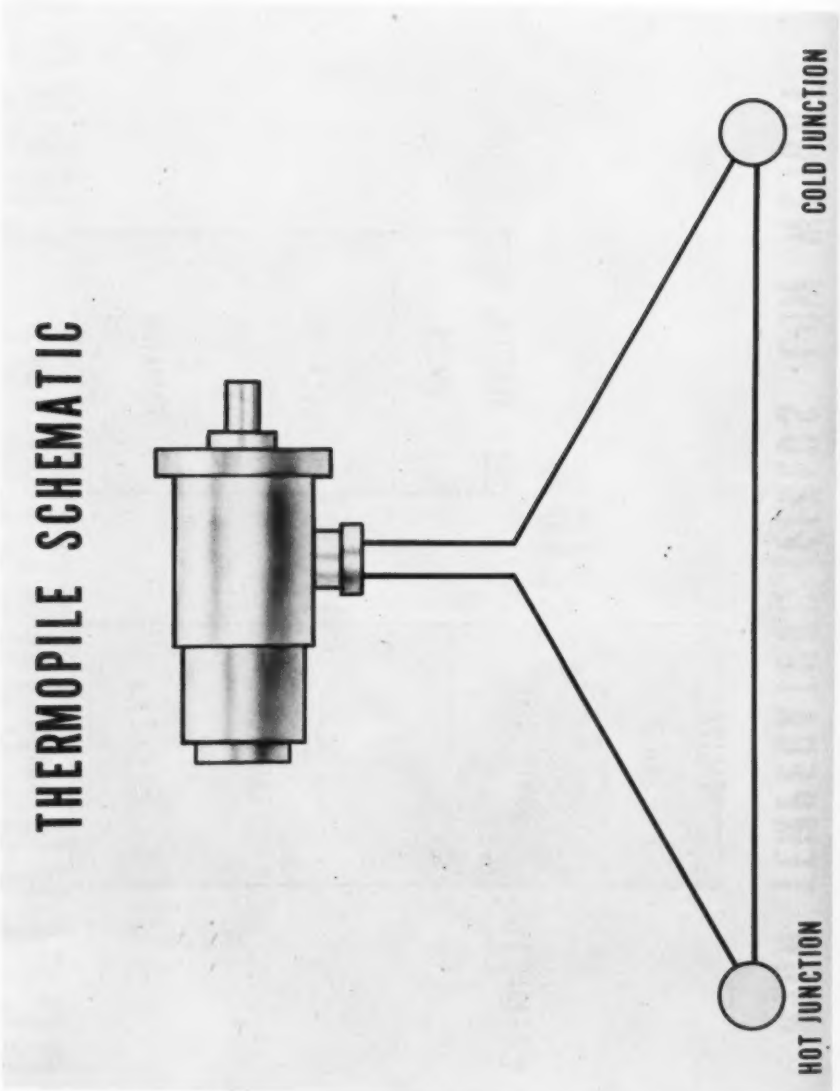
RADIOISOTOPE

FISSION

FUSION

HIGH TEMPERATURE YIELDS LOW WEIGHT



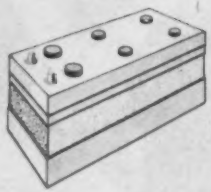

THERMOPILE SCHEMATIC
COLD JUNCTION
HOT JUNCTION

HOT JUNCTION

COLD JUNCTION

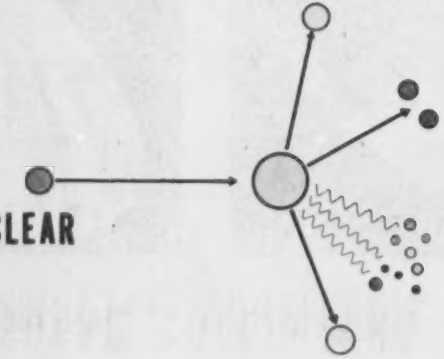
TYPES OF ENERGY SOURCE

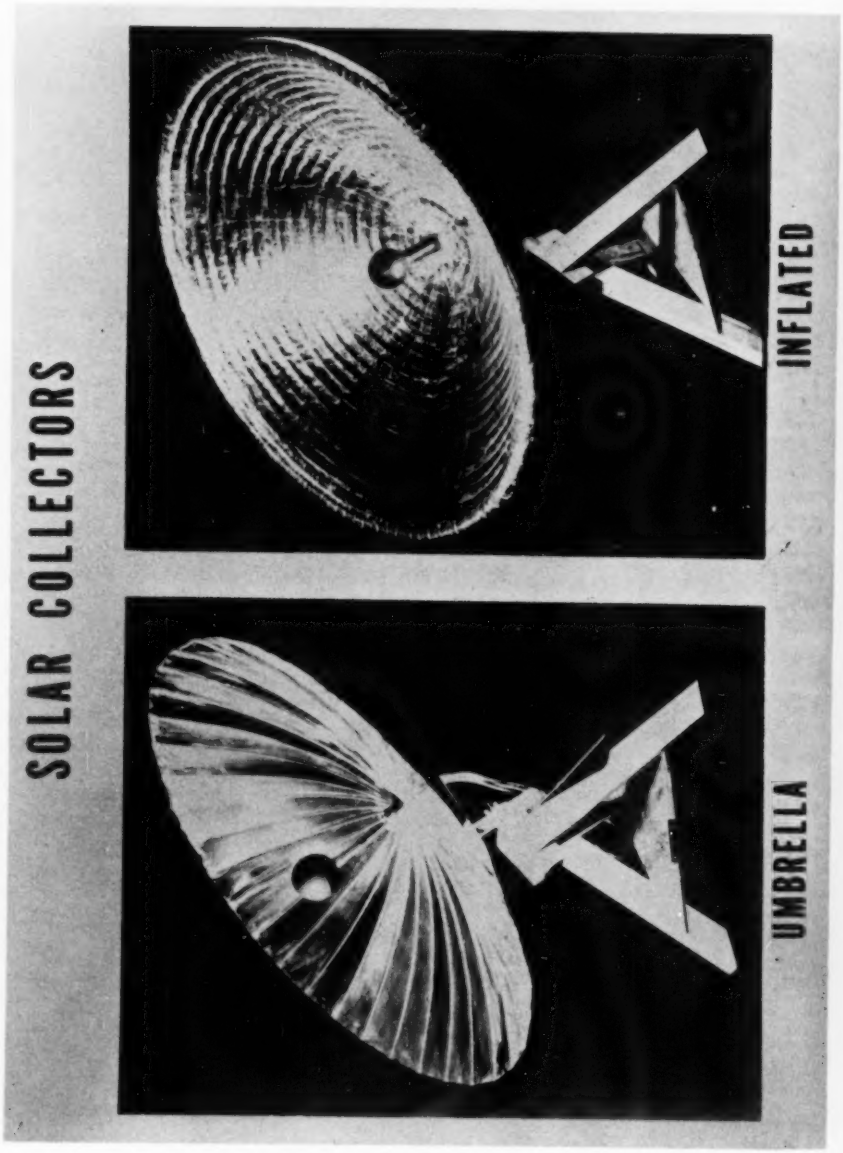
CHEMICAL

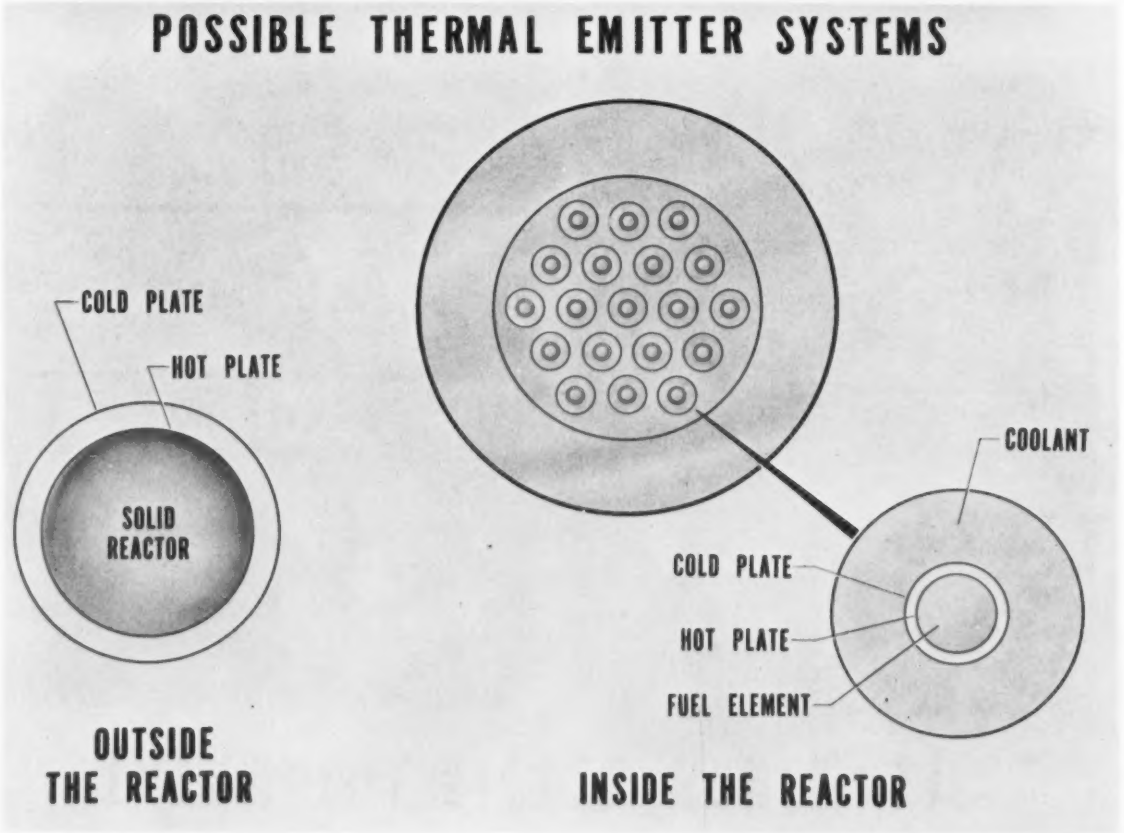


SOLAR

NUCLEAR




SOLAR COLLECTORS
INFLATED
UMBRELLA



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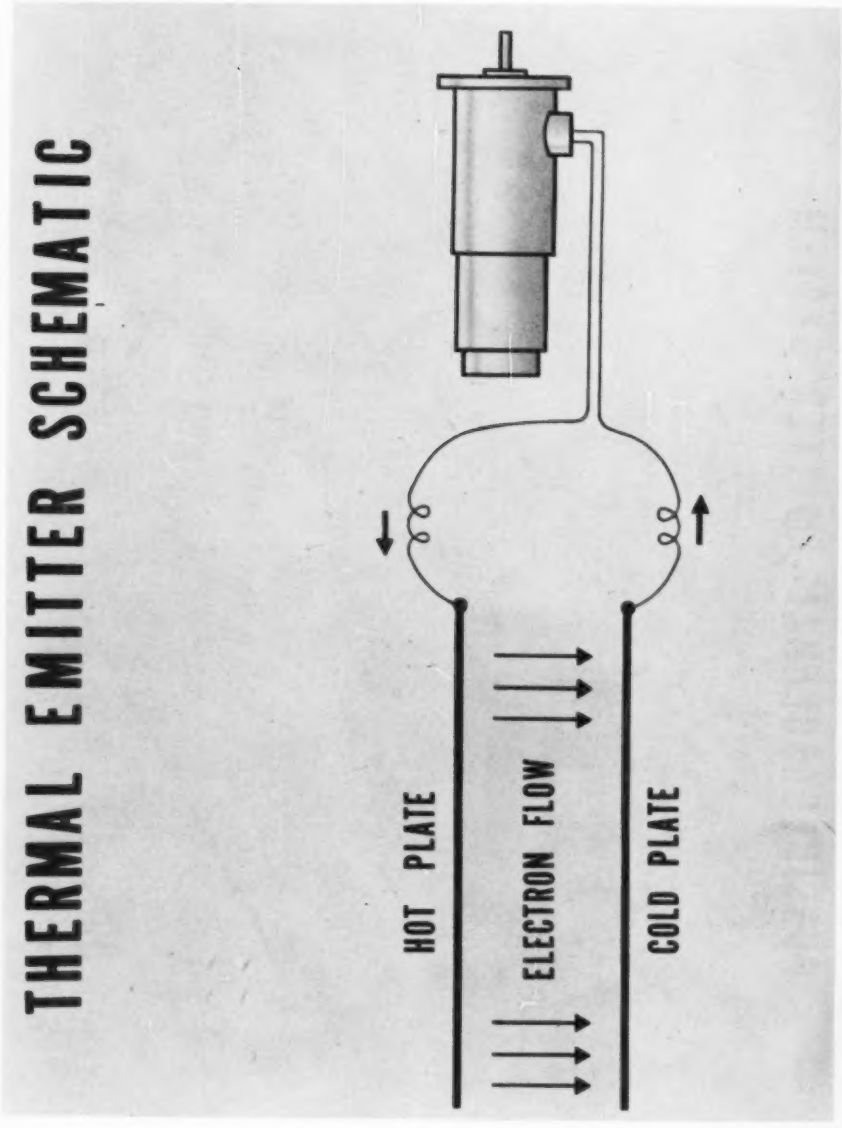
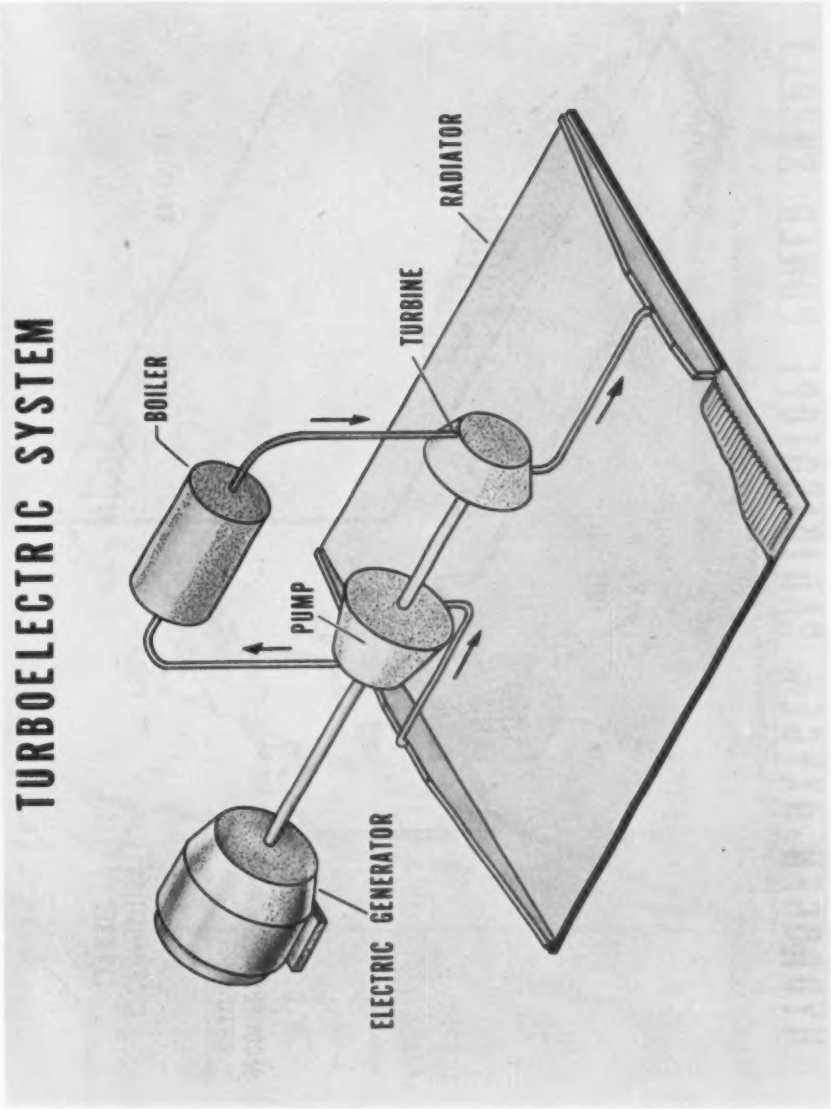
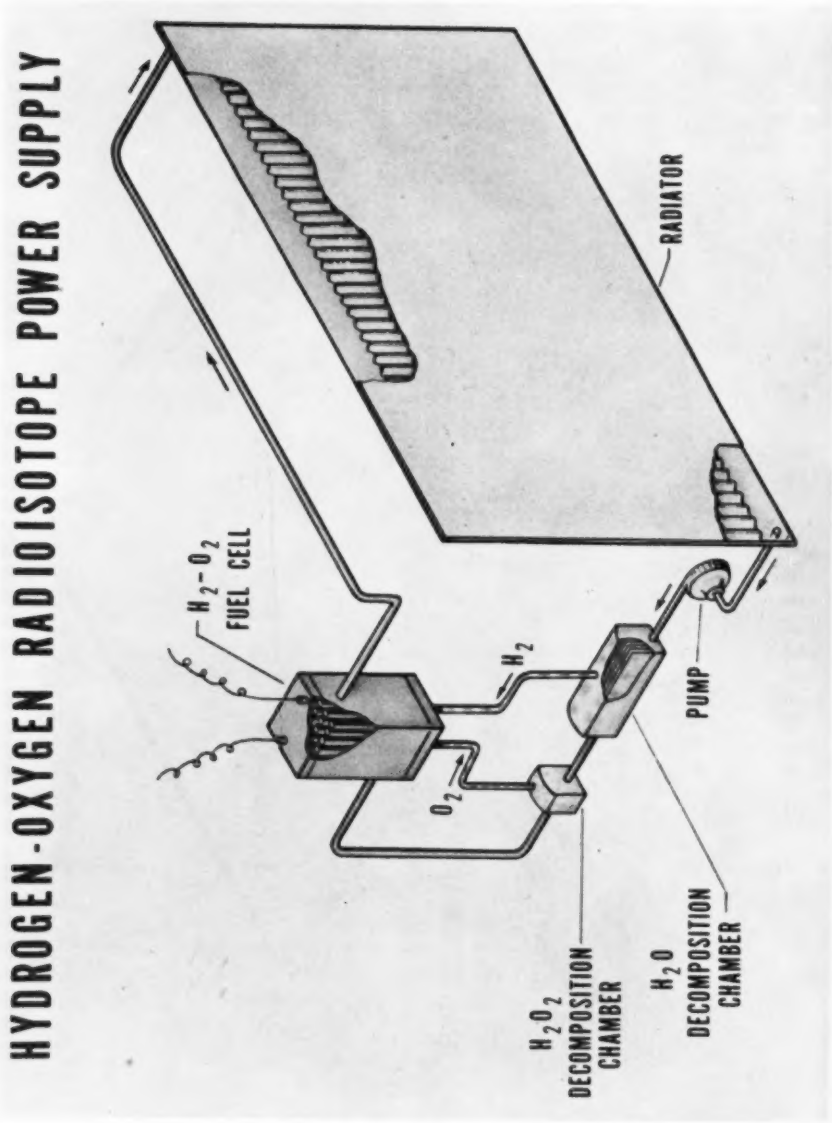
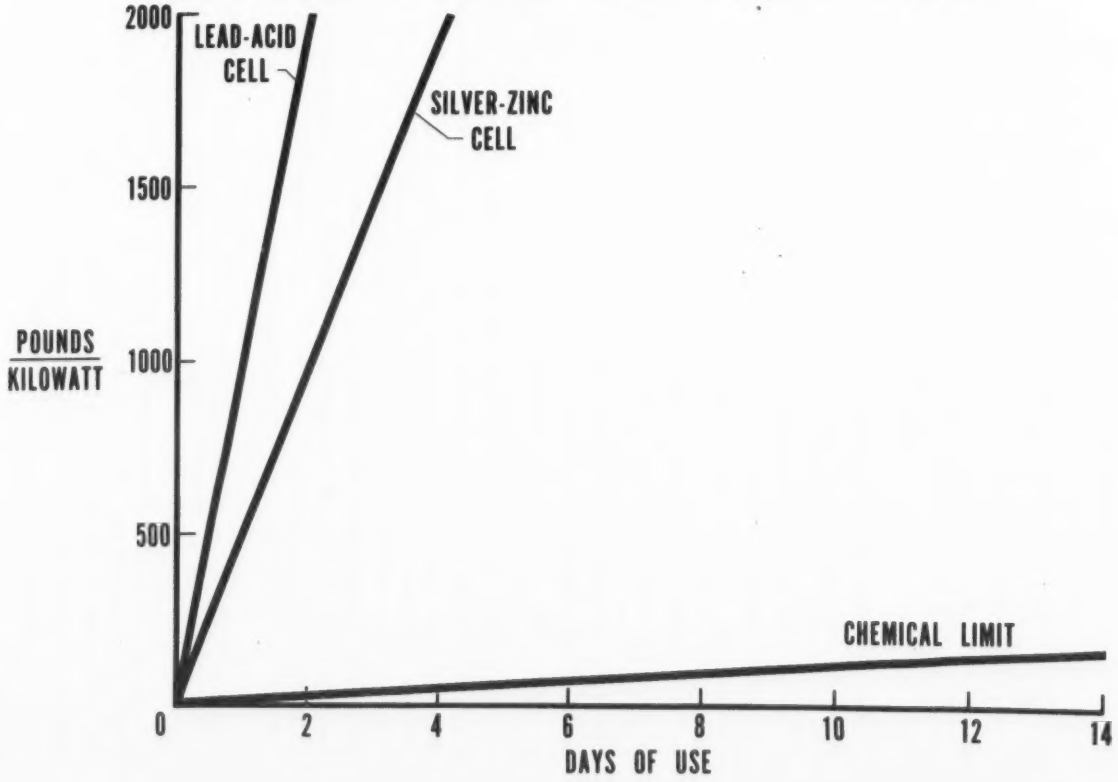

THERMAL EMITTER SCHEMATIC
HOT PLATE
ELECTRON FLOW
COLD PLATE


TURBOELECTRIC SYSTEM
BOILER
TURBINE
RADIATOR
PUMP
ELECTRIC GENERATOR


HYDROGEN-OXYGEN RADIOISOTOPE POWER SUPPLY
RADIATOR
H_2-O_2 FUEL CELL
H_2
O_2
PUMP
H_2O_2 DECOMPOSITION CHAMBER
H_2O DECOMPOSITION CHAMBER

CHEMICAL SYSTEMS FOR SHORT TIMES



Mr. HYATT. Mr. Chairman, we have one more speaker for about 10 minutes on nuclear rockets. I think after that would be a natural break.

Senator STENNIS. You mean after the next one?

Mr. HAYTT. After the next one; yes, sir.

Senator STENNIS. All right. You may proceed.

Mr. HYATT. The next witness is Mr. Harold B. Finger. He is the chief of the nuclear engines program at NASA headquarters.

Senator STENNIS. All right, Mr. Finger.

TESTIMONY OF HAROLD B. FINGER, CHIEF, NUCLEAR ENGINES PROGRAM, NASA

Mr. FINGER. Mr. Chairman and gentlemen, the subject of my discussion is space capabilities of nuclear rockets. The purpose of the discussion is to indicate why we feel that a research effort on nuclear rockets must be very actively pursued, and why we are doing so enthusiastically.

NUCLEAR FISSION PROCESS

To start with, we want to use the nuclear fission process in order to heat a gas and develop thrust. The nuclear fission process depicted here shows a neutron colliding with a uranium nucleus, splitting it into two main fission fragments which go off in opposite directions and which carry the major part of the energy of the fission process, about 90 percent of the energy. Also this fission process gives off about two more neutrons which then go on and collide with other uranium nuclei, producing a self-sustained fission process. Also we have radiation given off in the form of alpha particles, beta particles or electrons, and gamma rays. We must provide shielding to protect human beings and materials from these harmful radiations. In a fuel element in a nuclear reactor, we have dispersed uranium 235 atoms contained in another material. The colliding of these heavy fission fragments in this other material, produces heat, making this fuel element material extremely hot. We then put these fuel elements into a reactor shown here.

NUCLEAR ROCKET DESCRIPTION

Now, this is a sketch intended to show the nuclear rocket components. Here we have a propellant tank, and for the applications we are talking about, we will use hydrogen as the propellant because it is a low molecular weight fluid and gives a high thrust for every pound of hydrogen flow. The hydrogen is pumped out of the tank by a turbopump system, and then into the reactor. As this hydrogen passes through the reactor, past the fuel elements, it cools the fuel elements and absorbs heat from these fuel elements that is generated in the fission process. This hot hydrogen is then expanded or sped up. In going out this jet nozzle, it is sped up to velocities of about 25,000 miles per hour, and produces thrust. I have also shown here the kind of a shield that you might have in a space system to protect against this other harmful radiation (the alpha and beta particles and the gamma rays). Also shown here at the nose is the guidance for the system and the payload.

NUCLEAR ROCKETS GIVE HIGH SPECIFIC IMPULSE

Now, the reason we are enthusiastic about the nuclear rocket system is that it gives high specific impulse. That is, it gives a large amount of thrust for every pound of flow passing out through the jet nozzle. Here on this next chart, I have compared this ratio of pound of thrust per pound of flow of the nuclear with the chemical system. You can see the chemical systems give a maximum of about 400 pounds of thrust per pound of flow per second, whereas if we continually increase the temperature of the hydrogen in a nuclear reactor rocket system we can potentially get up to impulses in the order of 1,200 pounds of thrust per pound of flow per second. This is why we are interested in going to this nuclear system.

To indicate why the specific impulse is important, you can see, on this next chart, that high specific impulse gives low propellant weight requirements. In other words, if we get more pounds of thrust for every pound of flow, then we need less total pounds in order to let us accomplish the required mission. Here I have plotted the weight of the propellant in a rocket in percent of the total weight against specific impulse, pounds of thrust per pound of flow. You can see as we go to high specific impulse, this propellant weight decreases. If we go from 400, which is what we can get in our chemical systems, to 800, which is what we hope to get in our nuclear systems, the propellant fraction, the percent of the total weight of the rocket in propellant decreases from about 95 percent down to something like 70 or 72 percent. This means that the amount that is left increases, and the amount that is left is equal to the weight of the engine, the payload, and the structural equipment and tankage. The structure and tankage weight is about the same for the nuclear and chemical rockets. The question then is, does the engine weight increase so much that we do not gain anything in payload for the nuclear system over the chemical? If the engine weight increases too much in nuclear systems we do not gain anything in payload, and one problem is that nuclear engines are actually heavier, as shown in this next chart.

ENGINE WEIGHT

Here I have plotted the amount of thrust that we can get for every pound of engine weight for the chemical systems and the nuclear systems. In general, we can get about a hundred pounds of thrust per pound of engine weight from chemical systems, and somewhere up to a maximum of about 40 pounds of thrust per pound of engine weight in the nuclear systems. So you can see there is a ratio of about 2½ to 1 in engine weight. Then, in order to determine whether or not we can get an increased payload for nuclear rockets, we must analyze very specific missions to see if the reduction in the propellant weight is enough to overcome the increase in engine weight to deliver a certain thrust. On the next three charts, I have analyzed three missions.

EARTH SATELLITE BOOSTER

The first one is shown here. This is a mission of boosting an earth satellite vehicle up to a 300-mile orbit. I have specified that the satellite should weigh 30,000 pounds in a 300-mile orbit, and I have com-

pared the chemical and nuclear booster systems. The chemical system will weigh a little over a million pounds, and a nuclear system a little over 200,000 pounds. The chemical system will have three stages, whereas the nuclear could do the job in one stage. The size of the vehicles, you can see the diameter and length, are about the same because the nuclear stage uses hydrogen which is a lightweight fluid which takes up a large volume.

However, as you know, we are already developing a chemical system of about a million pounds gross weight in this million-pound engine that we will be discussing. We have not yet developed the nuclear system and, in fact, we are only in the early stages of research and development on this kind of a system. Also this is a difficult system to build because it requires very large reactor powers.

So, in general, for this earth satellite mission it appears that the chemical systems now being developed will take care of us for some time to come. If we learn how to build large-power, light-weight, high-temperature reactors, then this is a mission for nuclear power in which we would be interested.

INTERPLANETARY FLIGHT MISSION

Another mission of interest is the one in which we assume that the 30,000-pound satellite is a spaceship. The weight of a spaceship is 30,000 pounds, and we take off from an earth satellite orbit, and go out to Mars, just to hit or pass by Mars in a Mars probe. Here I show what kind of a payload we can expect for the chemical systems in green, and the nuclear systems in pink. For the minimum energy trip, the nuclear system will give a payload of about 11,500 pounds in this Mars probe, and the chemical high-energy system, which is the best we can do, will give about 8,000 pounds.

Now, this is the minimum energy trip, which takes about 260 days. It would be a long time to wait to determine whether or not we had had a successful shot. If we wanted to use excess energy systems or shorter trip times, you can see that the nuclear system shows a much bigger percentage gain over chemical systems. The nuclear systems will give 4,000 pounds of payload, and the chemical somewhere around 500 pounds. You have heard discussion of the Nova vehicle in which we cluster four 1½ million pounds of thrust chemical rockets together to give 6 million pounds. This Nova would be capable of putting into orbit 150,000 pounds, and we could then have a spaceship weighing 150,000 pounds in orbit.

The next chart shows what the capability of such a vehicle would be. Incidentally, it might look something like this. The reactor is shown here in red, two slabs of shielding to protect the tankage and crew compartment from radiation dosage; a long boom to separate the tankage and the crew compartment from the reactor. The tanks are shown in separated cylinders. Here is the crew compartment with antenna to send information back to earth, and a landing ship. In this case we are going to take off with this 150,000-pound vehicle to orbit Mars, and return to an Earth orbit. I have compared what we could expect with chemical and nuclear systems. The chemical system could deliver to the Mars orbit about 7,500 pounds whereas the

nuclear could deliver about 55,000 pounds. In addition, the amount of payload that could return to Earth then is only 750 pounds for chemical, and could be 25,000 pounds for the nuclear. In other words, the chemical system still could not carry a man out on this mission, whereas the nuclear system could, because this 25,000 pounds would be enough weight to return a manned vehicle to Earth. In addition, on this chemical vehicle there would be at least three stages, probably four stages. The nuclear could do this with a one-stage system.

I have indicated that these are calculations that we have made to indicate the potential of nuclear rockets and why we feel we should continue actively pursuing this effort. But there are many research and development areas to go through before we can get to the stage of actually flying one of these systems. I will not go through all of these shown on the chart except to emphasize that the major problem is still in the demonstration of reactor feasibility, and in this area, particularly, we are working very closely with the Atomic Energy Commission and, of course, the Los Alamos Scientific Laboratory on the demonstration of such reactor feasibility.

There are, then, these other areas of research and development. I have a model here that makes me say let us look a little at the turbopump problem. We have a contract out to develop a pump to be used on certain reactor tests at Los Alamos. In addition, at our Lewis Research Center we are developing various turbopump systems that might be applied to these nuclear rockets. One of them is indicated here. This has a single turbine rotor which takes the place of the three turbine rotors. What we do is simply pass the gas through the turbine three times in a cork-screw fashion. We can then use one wheel in place of three, so this is a three-stage turbine with one wheel. This is only indicative of the kind of research that we have going on at the Lewis Research Center of these components. I might mention also that many of these items are being worked on as part of our high energy liquid propellent rocket program, and these components are then applicable to the nuclear rocket system.

Getting back to the reactor feasibility, we will have discussion later in these hearings from the AEC on this particular point. It is the prime component in the nuclear rocket system and must, of course, have great emphasis. Thank you.

SPACE CAPABILITIES OF NUCLEAR ROCKETS

RESEARCH & DEVELOPMENT AREAS

REACTOR FEASIBILITY

TURBOPUMPS & PROPELLANT FEED SYSTEM

SHIELDING

RADIATION DAMAGE

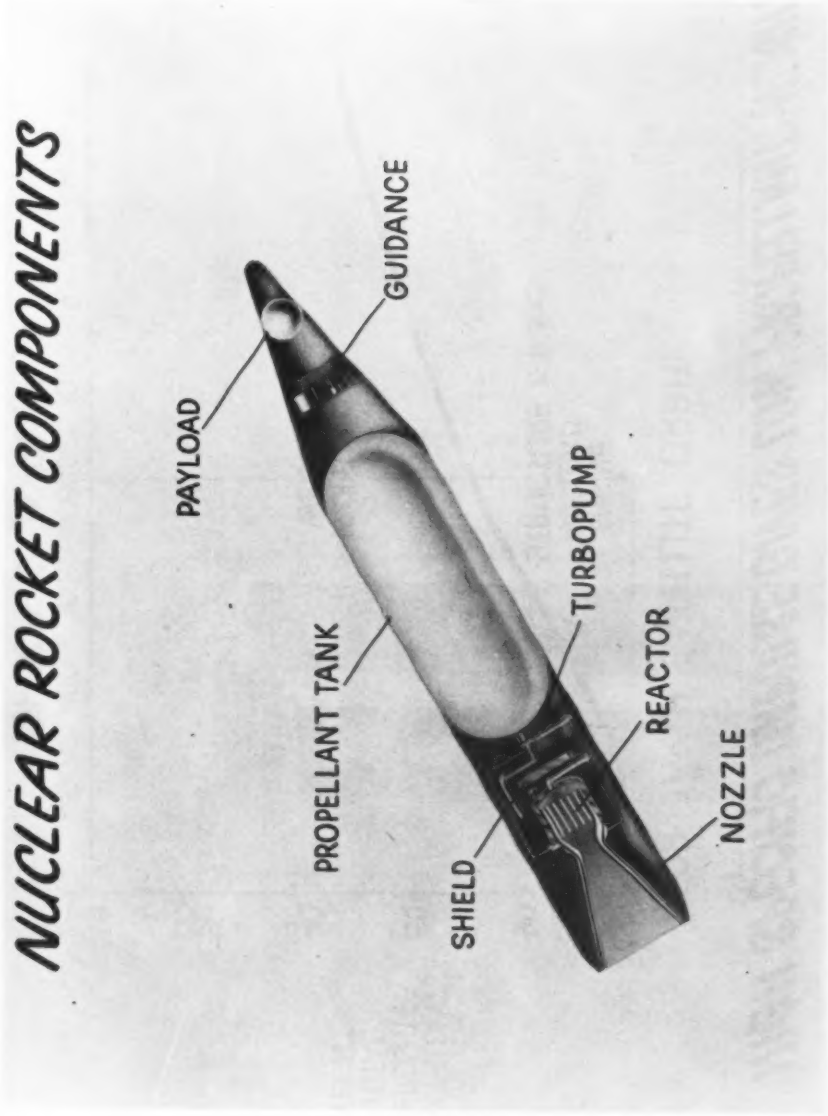
HIGH TEMPERATURE MATERIALS

HYDROGEN BOILOFF

FUEL ELEMENT DESIGN

JET NOZZLE COOLING

THRUST VECTOR CONTROL



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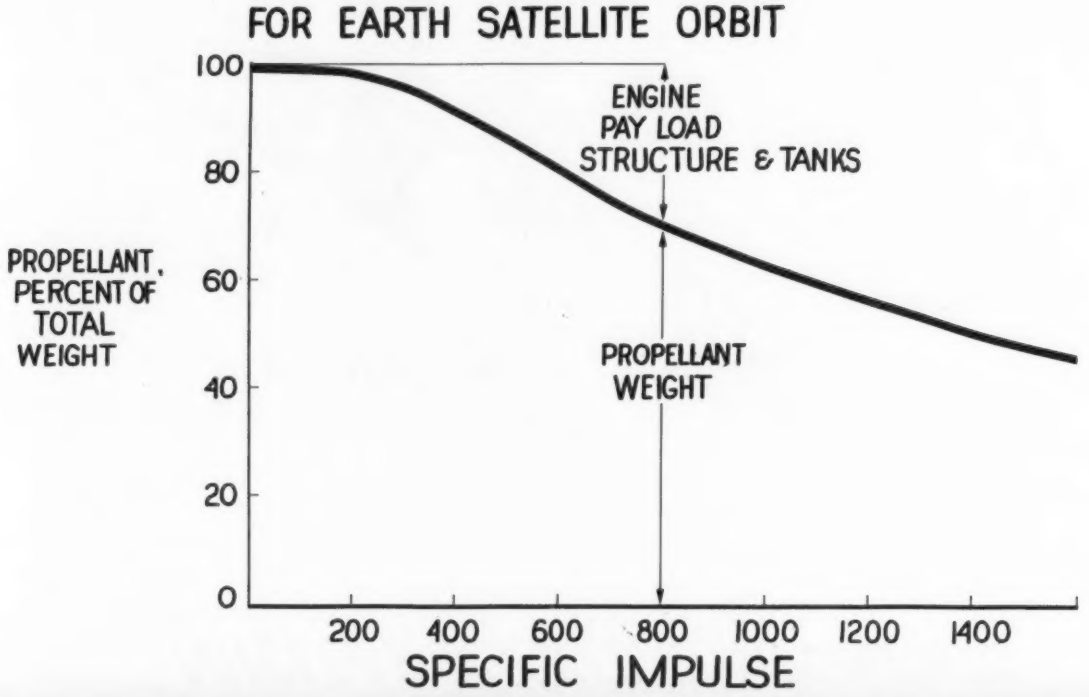
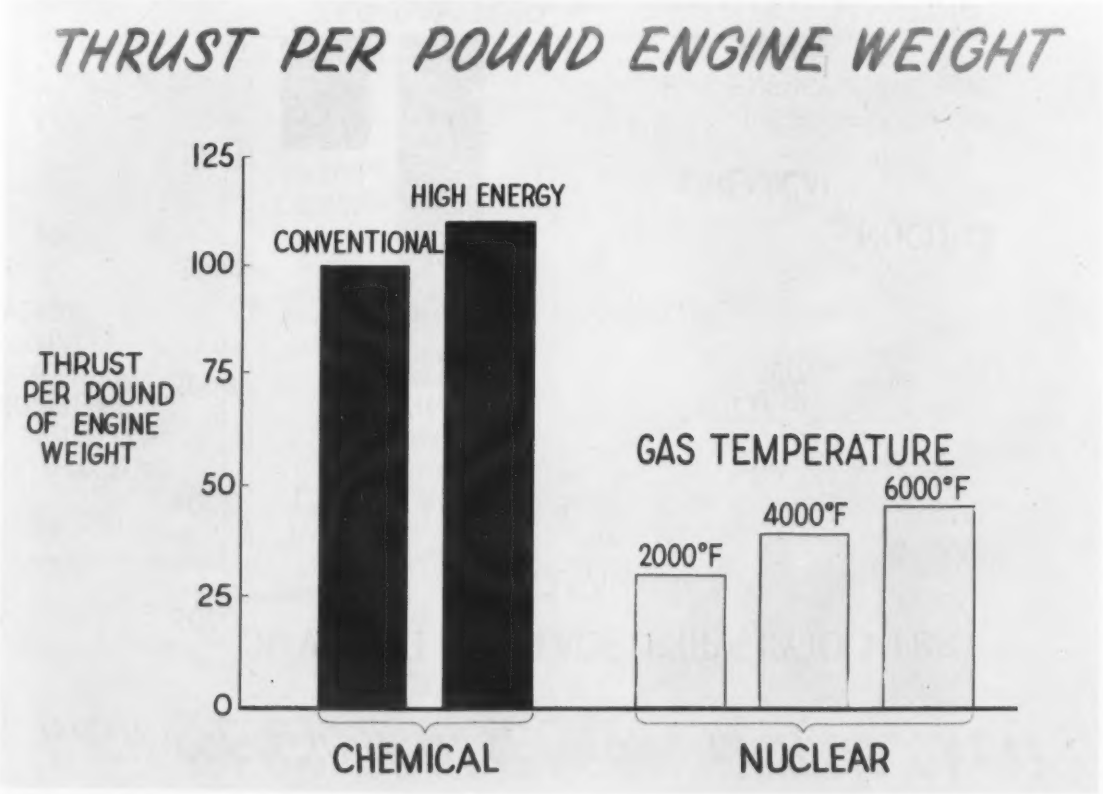
HIGH SPECIFIC IMPULSE GIVES LOW PROPELLANT WEIGHT



SPECIFIC IMPULSE



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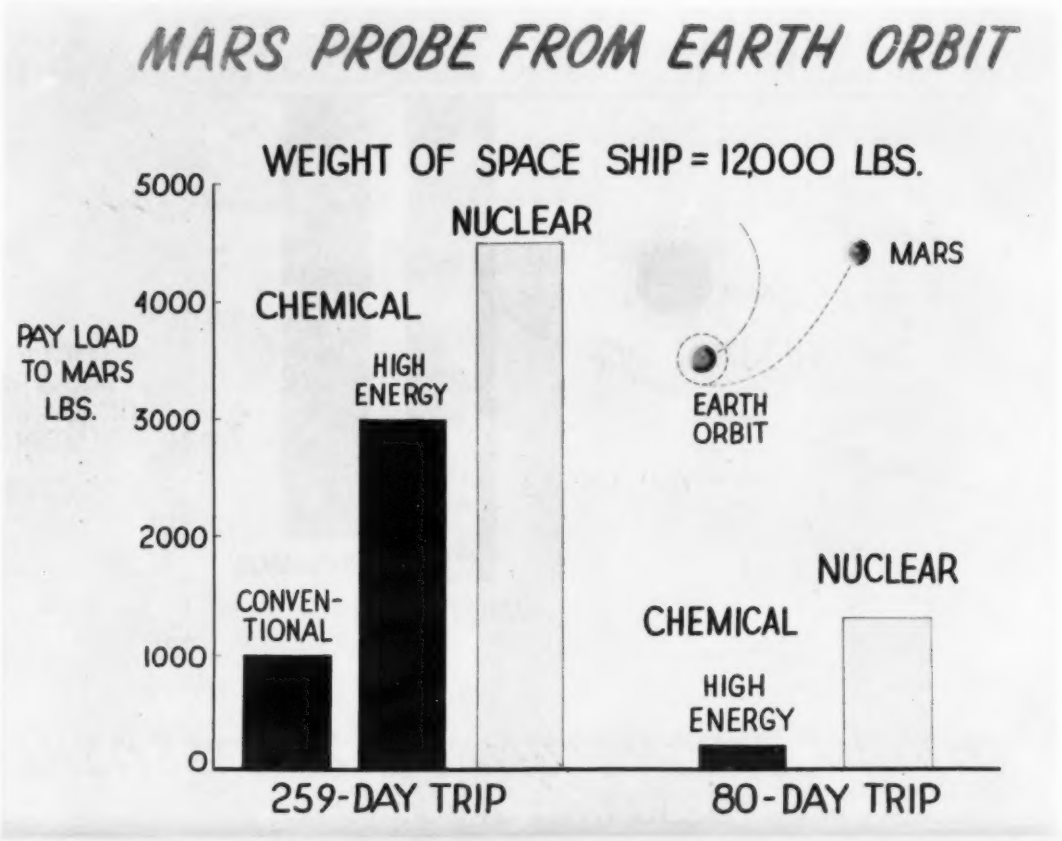
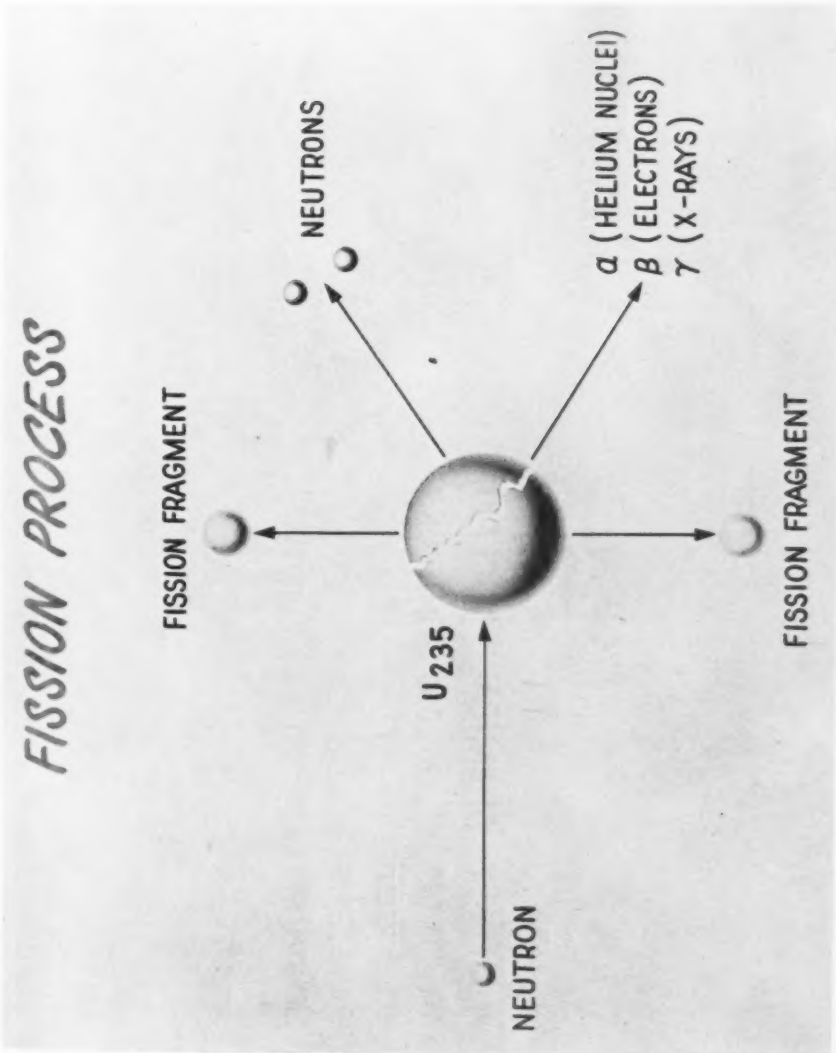

MARS PROBE FROM EARTH ORBIT
WEIGHT OF SPACE SHIP = 12,000 LBS.
PAY LOAD TO MARS LBS.
5000
4000
3000
2000
1000
0
NUCLEAR
CHEMICAL
HIGH ENERGY
CONVEN-TIONAL
MARS
EARTH ORBIT
NUCLEAR
CHEMICAL
HIGH ENERGY
259-DAY TRIP
80-DAY TRIP



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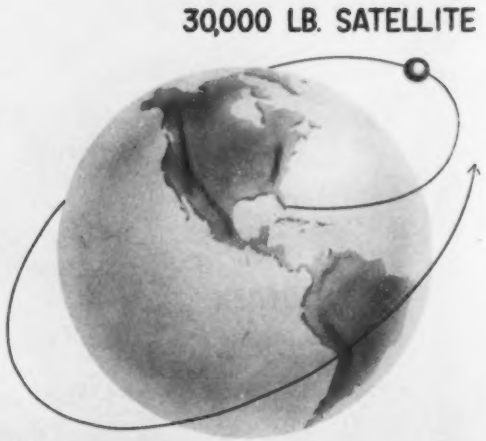
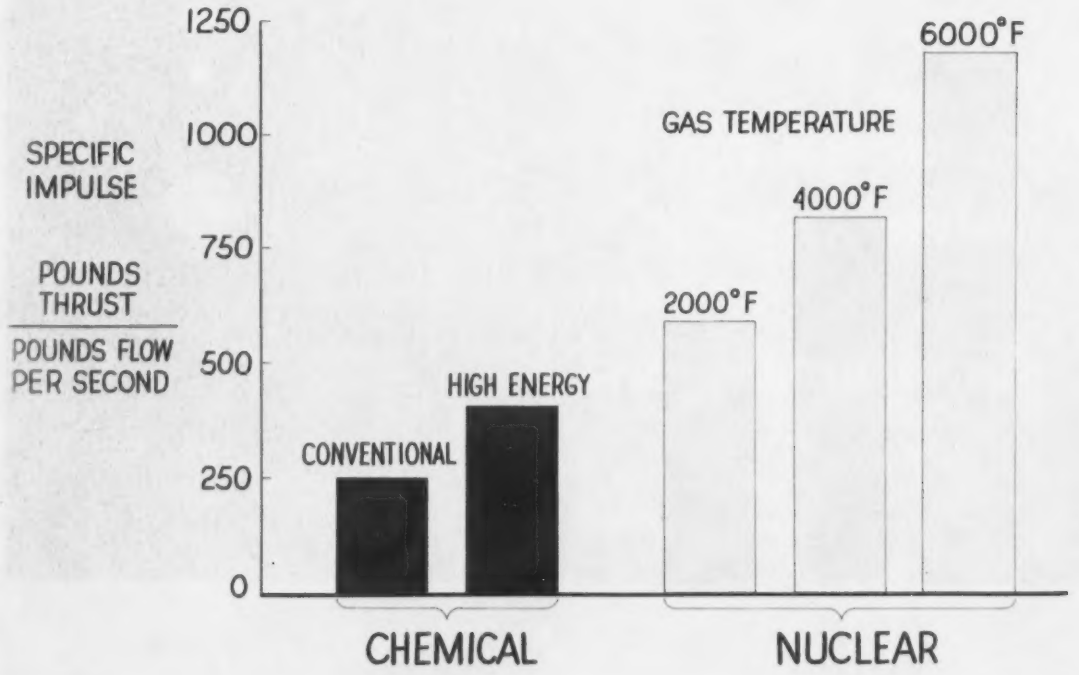
EARTH SATELLITE MISSION

	CHEMICAL	NUCLEAR
WEIGHT, LBS.	1,200,000	210,000
NO. OF STAGES	3	1
DIAMETER, FT.	17	21
LENGTH, FT.	170	170



NUCLEAR ROCKETS FOR HIGH SPECIFIC IMPULSE



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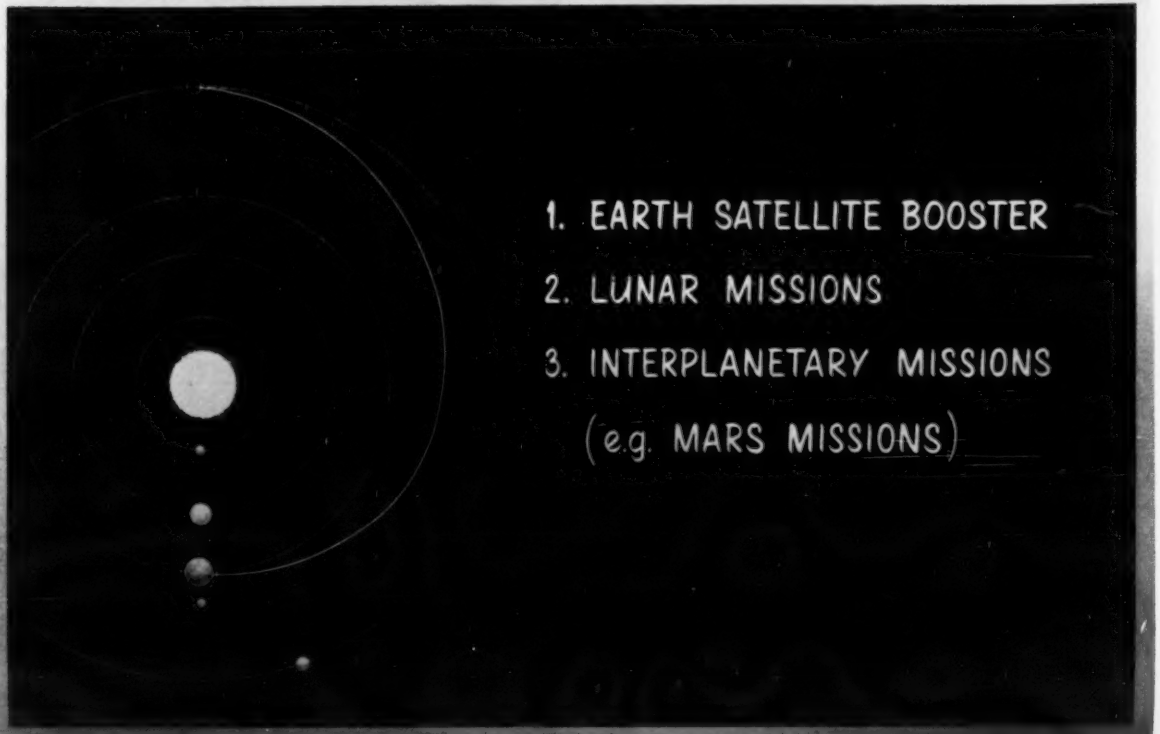
NUCLEAR ROCKET MISSIONS



MARS MISSION
TOTAL WEIGHT = 150,000 POUNDS
CHEMICAL NUCLEAR
MARS ORBIT PAYLOAD, POUNDS 7,500 55,000
RETURN PAYLOAD POUNDS 750 25,000

Senator STENNIS. Thank you very much. I am anxious that everyone have a chance to ask some questions now. I have one general question, and that is that something was said here about other experiments by private enterprise or corporations, as I understood it.

NATURE OF PRIVATE INDUSTRY SPACE PROGRAMS

To what extent are these different experiments that you have mentioned, so far as you know, being conducted by private industry? You mentioned the ionized chamber or the vehicle propulsion system. Are there others, do you know?

Mr. CHILDS. Yes, sir. For example, the plasma rocket. There are many possible plasma rockets. Industry is working with some of these, and we are working with some.

Senator STENNIS. Senator Young, I am going to call on you now.

Senator YOUNG. I have no questions at the present time, Mr. Chairman.

Senator STENNIS. All right. Thank you, sir.

Then, Mr. Childs, scattered through these programs here there are items that private enterprise considers valuable to them or worth going into or related to various military programs. Could you give us a little summary on that?

Mr. CHILDS. They are interested in these devices for exactly the same reasons that we are, and there are so many problems for work to be done on that that it takes more than one laboratory to get around to all the problems, so essentially we are working on some of the problems and they are working on others.

In some cases we are working on the same problems but with different approaches which appear warranted in these cases because the problems are difficult.

Senator STENNIS. Their program, Is it financed by them or are they subsidized in some way?

Mr. CHILDS. They are subsidized in some cases and in other cases it is financed by the industries involved.

Senator STENNIS. Well, we will not stop for it now, but I hope you can supply us with some detailed information on those projects because that is one of the things we want to get into and know just what the picture is.

(The following information was subsequently provided by NASA:)

There is no accurate accounting of every research project being conducted in private industry in which the National Aeronautics and Space Administration is also doing research work. Some of the major areas are: electrical propulsion and advanced propulsion concepts, plasma acceleration for propulsion, nuclear-electric power supplies for possible use with ion accelerators and the nuclear heated rocket.

Senator Martin, are you ready to ask some questions now on any of these subjects that were presented? My idea was that we could take the rest of the time for questions, and we will invoke the 5-minute rule on each member.

Senator MARTIN. Mr. English or Mr. Finger, neither one had his birthplace listed in this biographical sketch.

Mr. FINGER. Mr. Finger is from New York City.

Senator MARTIN. And Mr. English.

Mr. ENGLISH. Grand Rapids, Mich.

Senator MARTIN. I did not know why the two nuclear boys did not have their birthplace in here. [Laughter.]

FEASIBILITY OF NUCLEAR ENERGY USE IN SPACE TRAVEL

Did I get the right impression from the presentation of the nuclear data here that nuclear energy is much more practical or feasible for long-range travel in space than anything else we have?

Mr. FINGER. I think for the next generation of vehicles that we develop we can say that nuclear energy is probably the one that is of interest for long-range travel. In addition, as we go to longer and longer range missions, it gets to look better and better in comparison with the chemical systems.

Senator MARTIN. I got that from your presentation.

Mr. FINGER. Yes, that is correct.

Senator MARTIN. The longer your mission——

Mr. FINGER. The more advantageous.

Mr. ENGLISH. The two competitors are the solar and the nuclear, and the biggest question with the solar energy source is, Can the collector be a practical thing?

Senator STENNIS. The what?

Mr. ENGLISH. The collector, this big reflector.

Senator STENNIS. Yes, I got that.

Mr. ENGLISH. And it will have to be a rather fragile thing, and can you carry it up there, open it up satisfactorily? Will it be damaged by little meteroids knocking holes in it or will it finally wear away—that kind of thing—but it is a personal opinion of mine that nuclear energy does have the greater potential.

Senator MARTIN. Are any other witnesses prepared to dispute that point?

(No response.)

Senator MARTIN. That is all, Mr. Chairman.

Senator STENNIS. All right. Thank you, Senator Martin.

Senator Dodd?

Senator DODD. I have no questions.

Senator STENNIS. Senator Wiley?

RELATIONSHIP OF CHRISTOFILOS' MAGNETIC FIELD PREDICTIONS TO PROGRAMS UNDER DISCUSSION

Senator WILEY. I want that fellow who knows about it to tell me what Christofilos did. You are supposed to have someone here, sir, that knows. I want to know how it interferes with this program, if it does. For instance, I was told that what he accomplished has interfered with our radar system—practically put that out of business. Now, I want to know. If that is the case, how is it that you fellows—when you get to shooting up in the air, and they explode some of these bombs, what effect is it going to have on your engines?

Mr. ENGLISH. Can I tell you about that?

Senator WILEY. Yes, please do.

Mr. ENGLISH. I am not sure I can answer all your questions, but I would like to try.

Senator WILEY. Fine.

Mr. ENGLISH. This fellow Christofilos predicted that the magnetic field surrounding the earth would cause these electrically charged particles from the bombs to surround the earth in a certain fashion and, lo and behold, when they tried it out it did occur. It is not true that he was alone in this opinion, but it is a credit to him that he has been able to educate himself and to come to the position of knowledge that he has.

It appears to me that these electrically charged particles will not interfere with our propulsion systems. There are large numbers of charged particles in this area in any event. In particular, these Van Allen bands that have been discovered by the early satellites are present, and what this band of radiation that was put up by the bomb did was to actually accentuate the radiation, the charged particles that are present in these Van Allen bands. These will constitute somewhat of a hazard to space travelers and we will need to protect them against it by shielding. For example, we have considered if you go on one of these long Mars trips such as Mr. Moeckel described, these people will have a lot of supplies. One of the things they will have to have is a lot of water. We thought we ought to put this water around their crew compartment to protect them. This is one thing.

Now, it appears that with the Van Allen bands there we can send signals out. For example, they bounced a radar signal off Venus rather recently, and they earlier bounced one off the Moon. I expect this kind of thing interferes with communication in some areas, but will not completely blank it out and, in particular, I think the comment for the radar has arisen because they get spurious signals from the radar that are bounded off these conducting layers, but I think it does not completely rule it out.

Is this the kind of answer that you sought?

Senator WILEY. That is the beginning of it. What effect is it going to have on your engines—on your propulsion?

Mr. ENGLISH. I would say essentially none. If we can compare it, for example, with putting a nuclear rocket up or a device with a nuclear reactor in it, the intensity of the radiation that is already in space is rather low compared with that which surrounds the reactor.

In other words, if we put up a vehicle that has a nuclear reactor in it, it will itself have radiation that far exceeds that which we will find in space.

Senator WILEY. If what has been said is true—that it would neutralize the effectiveness of the radar system—why wouldn't it neutralize the effectiveness of other matters that you are talking about?

Mr. ENGLISH. Well, this would be interference with transmission of things like radar signals and radio and television—things of that kind. But it would not entirely eliminate it, prevent this communication, is my feeling.

You see, communication involves a variety of wavelengths. Let us consider visible light. These things we are discussing now are all a form of electromagnetic radiation. Light is one form. Radiant heat, radio waves, television and radar waves are all forms of electromagnetic radiation. You know on a foggy day you cannot see well because the light waves that you wish to see are stopped by the

fog. But a radar signal can penetrate this fog. I expect that when one class of frequency of radio communication is interfered with by this conduction band there will be another frequency that will be able to penetrate it.

Senator WILEY. Well, you will investigate further and see what its real danger is to your pursuing the course that you folks are on now—we found out in so many instances that we think we have gone ahead and have then gone up a dark alley, you might say; a blind alley. That is the very way that we arrive at knowledge, and in this particular instance I think it is very important because I feel—and I trust that my bringing this up to you will be such that you will understand the purpose for my bringing it up—that I, too, am simply a pursuer of truth.

Mr. ENGLISH. Yes.

Senator STENNIS. All right. Thank you.

Senator Cannon?

STATUS OF SOLID FUEL DEVELOPMENT FOR PROJECT SCOUT

Senator CANNON. Thank you, Mr. Chairman. Mr. Stoney, getting back a litle more to the immediate future rather than so far in the future, I would like to ask about progress being made with the Scout—is substantial advancement being made in the solid fuels that are used in the Scout?

Mr. STONEY. Well, the solid fuels that are used in the Scout take advantage of the advance in solid fuel rockets being made in the past year. These rockets—this rocket, for instance, was an early development of Polaris or an early trial of Polaris, and then we have taken that early trial and used the later Polaris fuel and obtained the rocket which has a nearly equivalent performance. This rocket is a new rocket that is being developed partially with some of the technology being developed for the Minuteman program. This rocket on the top is a rocket which was developed—has already been used on the Pioneer, and the Thor-Able shots, and will be used on the Vanguard, and this rocket is a scaled version of this.

I think you might say that these are the next to the latest solid fuel developments. They are not exotic, but they are right up to date.

BOOSTER RECOVERY

Senator CANNON. I believe you said that you were doing some work on the recovery of the first stage.

Mr. STONEY. I did not say that.

Senator CANNON. Did someone say that?

Mr. STONEY. Dr. Glennan says that this was one of the things they were working on for large space vehicles. When you have a tremendous booster, the question is whether you want to be able to get that back, if you can save money by doing it.

Senator CANNON. I see. I was going to ask what the state of the art is concerning the prospects of getting back the first stage. Are you prepared to answer that?

Mr. STONEY. I am not prepared to answer that one.

PROPULSION SYSTEM OF PLASMA ROCKET

Senator CANNON. Mr. Childs, on this plasma engine that you talked about, does it shoot a strong force out of the tail end of the engine just like the burning force that you see in chemical rockets?

Mr. CHILDS. Very similar. We use far less propellants in getting a given amount of thrust and force through this steam than with chemical rockets.

Senator CANNON. Does that give you a difference in pressure? Is that the thing that gives you the speed?

Mr. CHILDS. It is the same principle that you run into if you are standing in a rowboat as it comes up close to the shore. When you leap out on the shore, you go in one direction and the boat goes in the other direction. The fact that these charged particles are being expelled out and back with such high velocities means that the spacecraft has to be shoved in the opposite direction.

Senator CANNON. How far away do you think those engines are now from a practical standpoint?

Mr. CHILDS. Well, it is a little easier to make a prediction on the ion rocket, and this is just a prediction, a guess on my part. Perhaps we could have ion rockets in operation that have reasonable efficiency and give reasonable amounts of thrust in, say 3½ or 4 years. The plasma rocket looks like it will take longer to develop.

NATURE OF NUCLEAR ENGINE USE AND DEVELOPMENT

Senator CANNON. I notice there were two thoughts in this nuclear engine—one, that the nuclear engine was to be used as a booster or used in outer space, and also that maybe it was going to be used all the way. Is the idea there that it is to be used from the ground up?

Mr. FINGER. The first chart I showed is one which we used showing it from the ground up, and I indicated that this is actually a difficult application at this early stage of research on nuclear rockets, because it will require large power in the reactor.

Senator CANNON. That is with the thought of using it from the ground up?

Mr. FINGER. From the ground up.

Senator CANNON. How far in the future do you estimate that type of project is?

Mr. FINGER. Time? No, because we are in the research phase now; I do not think we can actually estimate time. I would only do it this way, by saying that I think the space application, where we started off from an orbit with a space vehicle, will be much earlier than this application and, as I say, I think it is one that will come along in the generation following the big chemical systems we have been talking about.

Senator CANNON. Do you know what success the Atomic Energy Commission is having now, or has had so far, with this engine they are working on or testing?

Mr. FINGER. Well, the AEC is not working with an engine; they are working with the reactor component for the engine, and tests have just been started which will be described in much greater detail a little later by Colonel Armstrong.

Senator CANNON. I see. Fine. Thank you.

Senator STENNIS. All right. Members of the committee, we have three very important witnesses here to hear in executive session, Colonel Appold, Mr. Tischler, and Colonel Armstrong, who will give some very factual testimony, I think. I have just one question, if I may ask Mr. Rosen, and we will go into executive session.

You spoke of a large meteorological satellite that was going to be operational and ready for delivery by the late fall of 1959?

Mr. ROSEN. No, Senator, I said 1960.

Senator STENNIS. All right. But did you say that it would carry 5,000-pound loads and stay up 6 months?

Mr. ROSEN. Yes, sir.

Senator STENNIS. Well now, when you say 5,000-pound loads, how high up is that and what is going to stay up and weigh 5,000 pounds?

Mr. ROSEN. Yes, Senator, that would be the payload in orbit at about 300 miles above the earth.

(Whereupon, at 4:15 p.m. the committee concluded the open hearing and thereafter went into executive session.)

[Executive hearing as cleared by the National Aeronautics and Space Administration—Classified information deleted]

NASA AUTHORIZATION FOR FISCAL YEAR 1960

TUESDAY, APRIL 7, 1959

U.S. SENATE,
NASA AUTHORIZATION SUBCOMMITTEE OF THE
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 4:15 p.m., in room 224, Old Senate Office Building, Senator John Stennis presiding.

Present: Senators Stennis, Young of Ohio, Dodd, Cannon, Wiley, Smith, and Martin.

Also present: Max Lehrer, assistant staff director; Everard H. Smith, Jr., counsel; Dr. Glen P. Wilson, chief clerk; and Dr. Earl W. Lindveit, assistant chief clerk.

Senator STENNIS. The next witness on my list is Colonel Appold. Colonel, would you come around, please.

Colonel APPOLD. Thank you, sir.

TESTIMONY OF COL. NORMAN C. APPOLD, ASSISTANT TO THE DEPUTY COMMANDER OF WEAPONS SYSTEMS, HEADQUARTERS, AIR RESEARCH AND DEVELOPMENT COMMAND, DEPARTMENT OF THE AIR FORCE

Colonel APPOLD. Mr. Chairman, and members of the subcommittee——

Senator STENNIS. We are glad to have you here.

Colonel APPOLD. I am acting this afternoon, Senator, in the form of a triple threat man.

Senator STENNIS. Yes.

Colonel APPOLD. I am representing the interests of three Government agencies, NASA, the Department of Defense in the form of the Advanced Research Project Agency, and my own service, the Air Force.

I hope in the few minutes' time that we have left this afternoon, that I can review for you a rather interesting project, one which was referred to earlier in Dr. Glennan's remarks, namely, Project Centaur. I will outline to you what the project objectives are; point out the reason that NASA has become interested in this project, the reason why the project was initiated, what it does, why it is possible, and give you a very brief outline of the project history.

I will outline in one brief chart the scheduled progress of this particular program.

Project Centaur represents the culmination of approximately 3 years of work which was conducted for the Government by the Air Force. It incorporates a technology that developed out of some classified work in propulsion and early weapons systems development.

That technology is the utilization of liquid hydrogen for aeronautical and space propulsion purposes. In the course of our presentation we will demonstrate why we wish to use liquid hydrogen, to give us the extra performance that it provides in space vehicle development and design.

Now the very first thing I should do is outline these objectives. Project Centaur is more than a propulsion development. You have heard several presentations this afternon which have outlined advanced propulsion development work. Project Centaur on the other hand is a new rocket engine development incorporated into an upper stage, with suitable payload and guidance, on top of a modified Atlas booster.

PROJECT CENTAUR OBJECTIVES

Let us look at the objectives. We have a requirement in the Department of Defense for a communications satellite placed in a 24-hour orbit carrying active communications gear, multichannel repeaters that can relay back to the earth's surface communications information and data that the military services or other Government agencies or indeed, ultimately commercial interests might use.

The purpose here is to place the maximum payload in orbit at the earliest possible date. An additional problem is to achieve reliability, and long life. We will attempt to get the largest payload weight the technology will permit, in the shortest possible time. The Strategic Air Command depends very heavily on a complex communication system which will permit direct radio contact with its aircraft on a worldwide basis. It is hoped that this 24-hour communications satellite which we will describe in detail will provide for SAC as well as other Government agencies that capability.

There arise several other advantages of Centaur. We wish to obtain the maximum payload capability consistent with available booster power for various lower altitude earth satellites, not just a 24-hour orbit, and Centaur can do this.

It can also extend scientific space exploration, providing higher payloads to the planets and the moon. Use of Centaur in manned space flight is also contemplated.

THE CENTAUR VEHICLE

Now let us briefly describe the vehicle itself. What is Centaur like? Earlier Mr. Rosen outlined to you Project Vega, and pointed out to you the utilization of the Atlas booster from the current missile program.

In Centaur we also utilize the booster technology that exists in this country. We place on top of Atlas within the same diameter of the booster body, another stage which contains rocket engines liquid hydrogen as fuel, and liquid oxygen as its oxidizer.

In the upper stage, covered by a protective nose cone, is the payload, which contains the communications gear. With an appropriate antenna structure it will relay the signals back to the earth as we mentioned earlier.

Now we can refer both to the chart, and more specifically to the model.

The chart demonstrates again the overall dimensions. Here on the table, so that you can see more clearly the configuration, I will describe both the outer features of the upper stage as well as some of the internal working parts.

Now, we can ask ourselves the question, Why did we use a high energy fuel? Why did we use hydrogen? Would it have been possible to use other propellent combinations? Indeed, we can do it many different ways, but as you recall, we designed this vehicle with three stages. We have plotted here a very brief explanation of how we utilize hydrogen to an advantage with a minimum of staging.

The point I want to make here is that propellent combinations of oxygen-kerosene which we are using today could not get us an equal payload into space at that distance away with an equivalent staging. Fluorine and hydrazine, which is also being investigated, could get us some lesser amount of payload into space. Centaur will achieve a better payload capability because of the greater amount of energy in the fuel, which is converted to useful thrust. At some future day we hope to improve this further by using a more exotic oxidizer—fluorine rather than oxygen.

Looking at it another way, we can see that the advantage lies in using oxygen and hydrogen. I have plotted here again a payload on the vertical axis and the distance away from the earth's surface in circular orbit on the horizontal axis. These two lines represent the payload weight variation in putting large heavy payloads in space at different altitudes with a vehicle of this kind. Now, it is not possible with other combinations of fuel and equivalent staging to get payloads that high.

I might point out, and will be discussing this in just a few minutes, that we attempted to earlier propose the Project Centaur concept for a reconnaissance satellite. But I will go through very briefly now the history of the program, to assure you that we are on the right track.

DEVELOPMENT OF THE CENTAUR CONCEPT

Work in liquid hydrogen started in the Department of Defense and other agencies prior to 1956. We have them listed here. The National Advisory Committee for Aeronautics had for years experimentally worked with liquid hydrogen in their laboratories, and the USAF and U.S. Navy both had engaged in design studies and experimentation. There were also members of industry working in this field.

Between the period of 1956 and 1958 significant progress was made. In that period of time there was initiated engine development by the Air Force with approval of the Department of Defense, and soon the USAF greatly expanded its support of engine and fuel systems development utilizing liquid hydrogen fuel.

One of the factors which had very seriously deterred the expanded use of liquid hydrogen in this country had been the limited quantities available. Since 1956 we have now built, completed and operated several very large liquid hydrogen plants.

With these large quantities available, we can now make substantial progress toward utilization of liquid hydrogen for a variety of space and aeronautical projects. In 1958, the Advanced Research Projects

Agency and the USAF initiated and supported Centaur. The NASA has very closely followed our developments and plans to continue the project in its 1960 space program.

I would like to point out very briefly a test and development facility to assure you that work is now going on at a very substantial rate. This area of some 7,000 acres in Florida, on which are located the Air Force liquid hydrogen plants, also is the location of a site owned by the Pratt & Whitney Aircraft Division, who has designed and is developing the Centaur liquid hydrogen rocket engine. This site shows the construction now being completed on two large rocket stands to test these engines through their qualification tests. I would like to state that the program is on schedule. Development contracts on the engine were initiated in October 1958, and on the vehicle with Convair in November 1958. Roughly $22 million have so far been invested by ARPA and the Air Force in this project.

That concludes my presentation.

Senator STENNIS. Thank you, Colonel. Senator Martin.

Senator MARTIN. No questions.

Senator STENNIS. Senator Cannon.

Senator CANNON. Well, it is a very impressive presentation you have made here, very, very encouraging.

Colonel APPOLD. Thank you, sir.

Senator CANNON. All right.

Senator STENNIS. We have one more witness, Mr. Tischler. Colonel, we thank you again.

Mr. HYATT. Mr. Chairman, I would like to say that it should be evident from the fact that these officers of the Air Force and the Atomic Energy Commission make presentation of cooperative programs that the NASA is working in very close coordination and collaboration with the various agencies.

Senator STENNIS. Yes, sir. It is encouraging to us to see you gentlemen and the agencies carrying on with such splendid cooperation. We want to commend you highly.

All right, Mr. Tischler.

TESTIMONY OF A. O. TISCHLER, CHIEF, LIQUID FUEL ROCKET ENGINES PROGRAM, NASA

Mr. TISCHLER. Mr. Chairman and gentlemen, my subject is the one and a half million pound thrust single chamber rocket engine. This is a development project sponsored by NASA.

Now, I appreciate the comments made by my colleagues earlier about the more exotic methods of travel, using devices such as the nuclear rocket, the ion rocket, the plasma rocket, which would be more efficient mechanically than chemical rockets. But there are times when the cheapest way to do a job is by truck, and this is a truck.

I would like to begin this discussion by discussing the capability of this million pound to million and a half pound thrust rocket in a vehicle. As you men know there is a vehicle being developed to use a million and a half pounds of thrust in the form of eight rocket engines. This cluster engine is under sponsorship by ARPA and is being developed by the Army Ballistic Missile Agency.

SINGLE CHAMBER ROCKET ENGINE CAPABILITIES

This single chamber rocket which I am about to discuss will develop the same thrust. It will be used in a vehicle known as Nova with a cluster of four such engines in the first stage with a single engine in the second stage. It is quite possible to substitute the cluster engine, million and a half pound vehicle, in the second stage.

ENGINE DEVELOPMENT HISTORY

Let me discuss briefly the negotiations that have taken place, the history of the contract which NASA has entered with Rocketdyne for the development of this engine.

On October 12, 1958, NASA sent invitations to bid to seven contractors. Five of these contractors responded. Their proposals were returned to us on November 24. A team comprising Air Force and NASA personnel, both technical and administrative, evaluated these proposals and selected Rocketdyne as the contractor with the best proposal and best prospect of development of this engine in a schedule of 4 years. The announcement of the winner of the contract was made December 12, and the final contract was signed on January 9.

ENGINE DESCRIPTION

Let's discuss the engine briefly. This is a model of the one and a million pound thrust rocket engine, and this rocket is presently about as accurate a description of the engine as that model of a man is an accurate description of a man. Nevertheless, it suffices to point out some of the main features of such an engine.

Propellants for the engine are taken from propellant tanks from the vehicle normally placed above this engine through a turbopump where the pressure is raised. The oxygen flows then directly into an injector which I will discuss briefly in a moment.

The fuel, which is in this case RP–1, flows from this turbopump through a manifold, then passes down the length of the chamber and returns to the injector. The purpose of this long passage of the fuel is to cool the walls of the engine, since the combustion process generates gases with temperatures of about 5,500° Fahrenheit.

This turbine is not a small thing in itself. It is again about the size of a 50-gallon drum, and it is driven by a turbine, and I will discuss that a little later briefly. The turbine, in turn, has to use gases which are created by a gas generator, this little red device here, and the generated gases are passed through the turbine to generate the power to drive the pumps and then through an exhaust duct from which they are exhausted into the exhaust nozzle of the rocket engine. The thrust mount is this little pad on top of the engine, and this transmits a load of 750 tons.

I have on the chart here a reproduction of this model. I want to point out the injector which is this circular cap right here below the thrust pad and the turbopump. I will discuss these two elements of this engine. This is a cutaway drawing of the injector, and we have within the dome housing, of this injector, a labyrinth through which pass the oxygen and fuel of the engine. They are then injected through ports into the combustion chamber, where the combustion takes place, of course. The flow through this injector is

nearly 3 tons per second. Now, in connection with a contract initiated by the Air Force with Rocketdyne to examine the feasibility of this engine, a contract which NASA has supported, an injector of the exact configuration shown here has already been run at thrust levels in excess of 1 million pounds of thrust.

This is a cutaway of the turbopump. We don't intend to go into too much detail here. The oxygen is taken from propellant tanks upstream through this element of a pump where the pressure is raised. The fuel enters this part, passes through a pump.

Now, to deliver this quantity of flow of oxygen and fuel, at these pressures, requires a turbine. This turbine, as I mentioned before, is driven by its own separate gas generator, which is about the size of some of the rocket engines we have already developed. So much for the description of the engine.

ENGINE TEST FACILITIES

I would like to discuss very briefly, since time is getting late, the facilities which we will use for the development of the million and a half pound engine.

Senator STENNIS. Yes, sir.

Mr. TISCHLER. These facilities are Air Force facilities, and the Air Force is cooperating to the fullest extent with NASA in the use of these facilities.

This facility is stand 1–A at Edwards. This stand is located at the Edwards Air Force Base in the Mojave Desert in California. This stand has been in existence for a considerable period of time and is shown on the next diagram right here, now with the tower removed. This is the stand which will be in use late this year or possibly early in next year in the testing and development of this million and a half pound engine.

Senator STENNIS. This is at Edwards?

Mr. TISCHLER. Yes. This second stand is being constructed by the Air Force presently. It is on this stand that our thrust chamber development work will be done. We require one more engine testing stand, and that will be stand 1–B, which is not yet in existence.

Senator MARTIN. These are the test stands at Edwards Air Force Base?

Mr. TISCHLER. All of these are located on Air Force property.

Senator MARTIN. Yes. This is the illustration that you had under discussion. This is the very site of the test stand we had under consideration in the supplemental authorization several months ago.

Mr. TISCHLER. That is exactly correct.

Senator MARTIN. This is the one in which we see they are really carrying out an extensive program in cooperation with the Air Force.

Senator STENNIS. Yes.

Mr. TISCHLER. That ends my discussion.

Senator STENNIS. We are very glad to have you tell us about that.

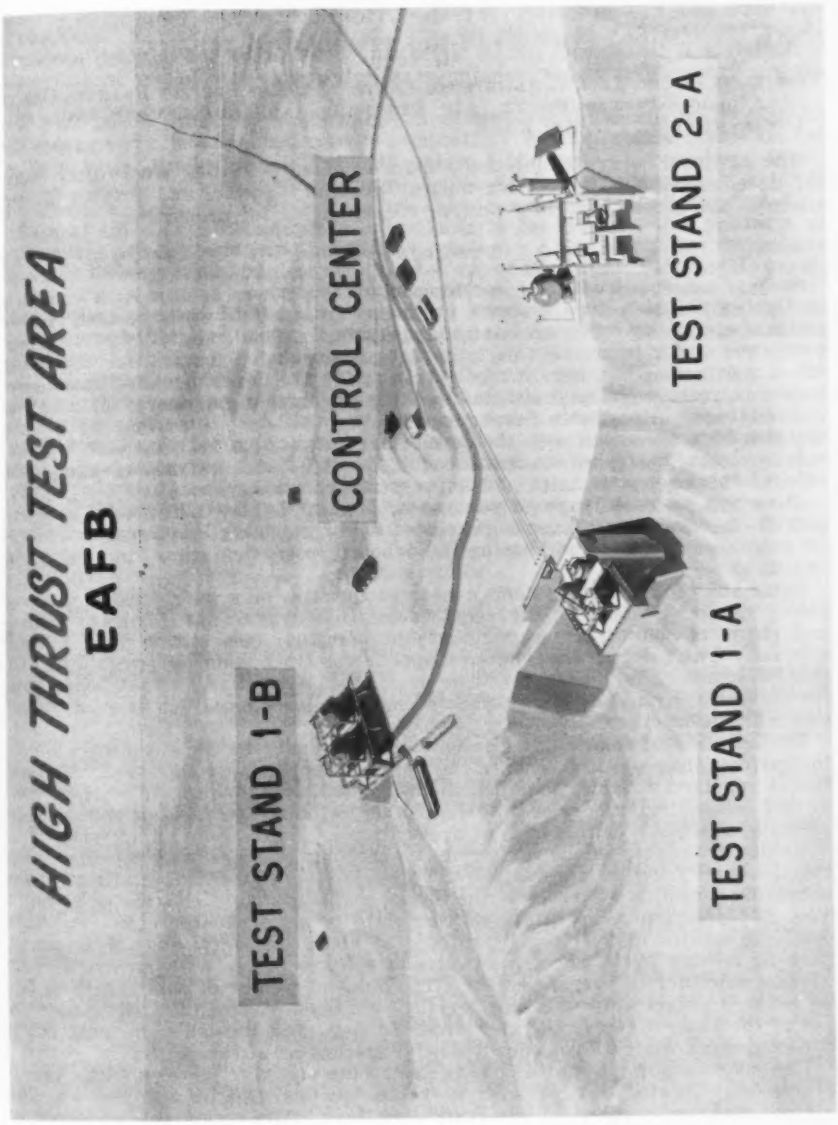
Senator MARTIN. Yes, we need to know that now.

Senator STENNIS. All right, continue with anything that you have. It is very interesting.

Mr. TISCHLER. Gentlemen, that closes my discussion, and I am willing to answer any questions you may ask.

THE 1½ MILLION POUND THRUST SINGLE-CHAMBER ROCKET ENGINE

EDWARDS
AIR FORCE BASE
ROCKET TEST
STAND 1-A


HIGH THRUST TEST AREA
EAFB
TEST STAND 1-B
CONTROL CENTER
TEST STAND 2-A
TEST STAND 1-A

Senator STENNIS. All right.

Senator Martin, do you have anything further?

Senator MARTIN. No.

(At this point in the hearing, a presentation was made on space-oriented missile activities of the Atomic Energy Commission. A short, unclassified synopsis of this presentation follows.)

TESTIMONY OF COL. JACK L. ARMSTRONG, CHIEF, MISSILES PROJECT BRANCH, OFFICE OF ATOMIC NUCLEAR POWER, AIR RESEARCH AND DEVELOPMENT COMMAND, DEPARTMENT OF THE AIR FORCE

The Atomic Energy Commission's space oriented activities are Project Snap, for development of systems for nuclear auxiliary power, and Project Rover, aimed at the development of a nuclear rocket engine for propulsion.

PROJECT SNAP

Snap is concerned with the development of low power devices with emphasis on lightweight, long-lived systems, producing from a few watts to several kilowatts of electricity and increasing the operating life and reliability of auxiliary power source for instrument packages in satellite and space probes. The Snap effort is following two heat source avenues: (1) the development of small compact core reactor powered systems and (2) the use of the energy of decay of radioisotopes. Along with developing these two sources of nuclear heat, Snap has also been concerned with the development of reliable heat-to-electricity conversion techniques such as advanced lightweight thermodynamic equipment, efficient thermoelectric units, and improved thermionic systems.

For every pound of payload put into orbit around the earth, several hundred pounds of rocket thrust must be provided. This puts a high premium on keeping off extraneous weight and keeping the onboard instrumentation functioning for as long as possible.

Solar and radioisotope systems appear competitive on a weight basis, in lower power ranges. For short life requirements below a 60-day lifespan, battery and chemical sources are capable of but marginal competition with nuclear systems. Our present Snap devices appear easily capable of 1-year life. On this lifespand basis, nuclear systems are indeed attractive. Even longer lives for nuclear systems are to be presumed as development and engineering refinements are incorporated.

The unclassified snap 3 unit (announced in January by the President) serves to illustrate the scope and tenor of the work that is being accomplished. Because it was readily available, polonium 210 was used as the source of nuclear heat in this demonstration device. Several other radioisotopes are, of course, suitable and available for this type of application as I will show later.

Radioactive decay of the fuel serves as the source of heat and provides a hot thermocouple junction temperature of approximately 700° F. Radially arranged about the central heat source is the thermocouple system consisting of 20 units. The cold junction temperature of the units is approximately 180° F. Each couple generates an electromotive force of about 0.1 volt. Snap 3 produced, with no moving parts, about 3½ watts of electric power with an overall conversion efficiency of over 6 percent. The 5-pound weight of this generator can be reduced appreciably with engineering refinements. Snap 3's significance is not of the same order as the glow from Edison's first incandescent lamp but it does represent what we consider a solid technological advance.

Radioisotone power sources such as Snap 3 are suited to power a whole gamut of remotely located devices such as radio beacons, fallout and fire warning alarms, and meterorological observation stations. The sorely needed empirical investigation of the oceans of the world might well generate a need for radioisotope derived electric power for submerged instrument packages. Radioisotone power can better perform many of our difficult tasks in unusual environments, making possible feats heretofore thought impossible or impractical.

Cost is always an important consideration in attempting to estimate future applicability of radioisotope power sources. Naturally the more units built, the cheaper they will become. A distinction must be made between the costs of the nonnuclear components of the power source (conversion system and ancillary hardware) and the cost of the radioisotope itself. Nonnuclear costs will be nominal, depending on the type of heat-to-electricity conversion equip-

ment chosen. Cost of the radioisotope is another matter. This cost reflects the nature of radioisotope production processes, depending on whether it is recovered from the fission product waste stream of a reactor or whether it is produced by special irradiation. Some radioisotopes are already being produced quite cheaply; others that seem to have power producing futures must await development of large scale production or separation facilities before becoming economically feasible. Assurance of the availability of radioisotopes would stimulate demand for radioisotope power producing devices. Firm generator requirements would stimulate interest in making scarce radioisotopes more plentiful.

A good power producing radioisotope must conform to certain limits of half-life energy and type of radiation to be acceptable. When practical limits are set on these power producing requirements, only a few appear to be usable.

Final selection of any particular radioisotope is based on the use for which it is intended and the availability of that radioisotope in the quantities required.

Several suitable radioisotopes are available in the fission waste products of our central power station and production reactors. At present these wastes are stored in underground stainless steel containers at Commission sites. However, some of the radioisotopes from fission waste products are now being separated at the Commission's Fission Products Pilot Plant in Oak Ridge. Separation operations of the plant currently are directed toward large-scale concentration of Serium 144 for use in the Snap program.

Based on an estimate of our U.S. reactor, by 1975 fission waste streams will contain radioisotopes capable of generating 50,000 thermal kilowatts. Assuming an electrical conversion efficiency of 10 percent, this amounts to approximately 5,000 kilowatts, or enough to supply the electrical power needs of approximately 5,000 normal American families. Although present technical difficulties accompanying any large scale effort to reclaim and utilize this heat appear difficult, the success of Snap 3, a working piece of hardware using a radioisotope heat source, reminds us that with ingenuity something can be done to reclaim and use this energy.

PROJECT ROVER

Project Rover is the code name for the AEC work on developing a nuclear rocket engine.

The basic difference between chemical and nuclear propulsion systems is in the method of obtaining propulsion energy. In chemical systems, energy is imparted to the working fluid or reactive mass from the combustion or decomposition of fuel or propellant. The working fluid in a nuclear system provides no intrinsic energy but is simply brought to high temperature by the kinetic energy released in a controlled fission process within the nuclear reactor.

Project Rover, a joint AEC-NASA effort, established in the AEC in 1955, is pointed toward the demonstration of the feasibility of applying nuclear energy to rocket propulsion applications. Technical work is centered at the Commission's Los Alamos Scientific Laboratory. Upon the formation of the National Aeronautics and Space Administration, responsibility for development of certain non-nuclear Rover components were transferred from the Air Force to NASA. This includes the propellant feed system pump development by Rocketdyne.

Since very high temperatures and high heat fluxes are required if interesting propulsion performance is to be attained, Rover's gas cooled reactor will function at temperatrues limited only by materials utilized. Because of this, much of our AEC technical effort to date has been expended in advancing the state-of-the-art in materials and fabrication techniques. We would like to know the physical, chemical and neutronic properties of materials over a wide range of temperatures. Our missile oriented effort has required development of talents and facilities to permit extensive reserach in high temperatures, chemistry, metallurgy, fluid dynamics, neutronics, control analysis and mechanical design.

Rover, being a rocket, must carry its own reactive mass or working fluid which is heated by the reactor and expended to produce thrust and requires application of extreme power for only a few minutes. Testing of experimental Rover reactors will be done at the AEC's Nevada test site.

For reactor tests, we are using a 480 square mile area west of the weapons test area known as Jackass Flats. This area is sufficiently isolated and buildings are so situated that there will be no hazard to personnel in operating and experimenting with test reactors. Rover activities at Los Alamos consist of three major efforts; one, the development of special test reactors which explore

the problem of high-power density and high temperatures; two, the development of high temperature materials for such reactors, and three, the investigation of new concepts for conversion of energy into useful propulsion forms. This work at Los Alamos will lead to a series of test reactors which will be operated at the AEC Nevada test site under specific test conditions of temperature, pressure and power density.

Our first Rover reactor is the Kiwi-A which is in Nevada now, being checked out with its associated test and control equipment. We expect to initiate power runs on this reactor, sometime this summer. Kiwi-A operates on an open cycle where the propellant (hydrogen gas) heated in the reactor core is expanded thru a nozzle to the atmosphere.

The plan is to operate the reactor at a variety of power and temperature points, study its transient response characteristics, and check out the ancillary diagnostic and control instrumentation. After testing, the reactor will be dismantled in the MAD building and components examined. If successful, the Kiwi-A test will be a concrete step in the practical evaluation of this type of propulsion reactor.

This reactor is a long way from fully utilizing the potential capabilities of nuclear energy. We are continuing our basic studies, on nonconventional reactor concepts in which the temperature and specific impulse of the system will be much less limited by internal structural considerations. In fuel element development, fissionable materials are combined with structural or dispersing materials. How these compounds behave under reactor operating conditions must be determined and we must develop the ability to fabricate materials into required shapes.

During operations, the reactor gives up its heat to a propellant which is roaring through the reactor at high pressures and velocities. Studies of corrosion, erosion, high temperature reaction rates and thermal and mechanical stresses are a part of the development effort.

Since we can eventually expect nuclear performance in the order of 300 percent greater than that from chemical rockets, nuclear rocket engines look very attractive for extended orbital missions and interplanetary explorations. Depending on the specific missions, this higher rocket performance represents a significant reduction of gross missile weight and required takeoff thrust.

I would like to reemphasize that our work in developing gas cooled reactors is also making considerable technical contributions to general field of reactor technology. We are learning a great deal about the properties of high temperature materials and we are learning something of the limits to which uranium bearing materials can be utilized. These data will not only be applied to the propulsion field but will help increase the efficiency of power and other special purpose reactors.

In this brief review of our space oriented nuclear programs is a resume of the progress we are making toward early demonstration of the feasibility of applying nuclear energy to space missions.

Senator STENNIS. Mr. Lehrer, proceed with your questions.

ENGINE TEST STANDS AT EDWARDS AIR FORCE BASE

Mr. LEHRER. Mr. Tischler, will you tell us what the distances are between the various test stands of that complex at Edwards Air Force Base?

Mr. TISCHLER. This distance is approximately 1,000 feet. This distance from stand 1–A to stand 2–A is approximately 1,000 feet. Now these distances are insufficient to afford blast protection with the propellent quantities that will be in use on these stands in straight line of sight distances.

However, what doesn't show on this drawing satisfactorily at all is the fact that there is a hummock or hill at this location which prevents a line of sight from this site to this site, and again there is another substantial mound of dirt in this location which prevents a line of sight between these stands, so that none of them can see the other. A study—a careful study has been made of these distances,

and there is good indication that there is adequate blast protection from stand to stand.

The clustering of these three engine test sites around one control room means that we can avoid duplication and rather costly instrumentation in this control room, and it will also facilitate loading of oxygen and fuel from a centrally located source.

Mr. LEHRER. Has it ever been envisaged that more than one stand would be operated at one time?

Mr. TISCHLER. It is most unlikely that there will be more than one firing at a time.

Senator STENNIS. I was wondering why you have so many there.

Mr. TISCHLER. A development program such as this entails a lot of test work. There are stands here which will be used initially in chamber testing, and these also will be used in chamber testing. A test of a chamber is something of 2 weeks' undertaking during its development phase. Our progress has to be faster than once every 2 weeks.

Senator STENNIS. So you have several tests going on all the time?

Mr. TISCHLER. This stand will later be converted to an engine test stand. This is our engine test stand but it is not likely to be available before January 1961, and we need it rather badly.

Senator MARTIN. These will not be in operation during construction and development?

Mr. TISCHLER. The schedule for this stand is late in this year, and this is late 1960. We expect to use it by January 1961.

Senator MARTIN. But they are being developed, they are under construction?

Mr. TISCHLER. This stand exists; this stand is being built; this stand has the ground cleared and there is nothing much more there. It is being designed presently.

ENGINE OF OVER 1,000,000 POUNDS THRUST ALREADY TESTED

Senator STENNIS. May I ask a question? What thrust do you have now? You talk about a million and a half here. You now have what?

Mr. TISCHLER. The chamber with injector has been tested in excess of a million pounds already, and the engine is designed to be rated at a million and a half pounds when it is in final form.

Senator MARTIN. Mr. Chairman, I have to leave at this point.

Senator STENNIS. I understand, Senator Martin. Thank you. I appreciate your staying here.

SOLAR BATTERIES USED IN VANGUARD SATELLITE

You were talking about this solar power a while ago, Mr. Hyatt, is that in the Vanguard?

Mr. HYATT. Vanguard has solar batteries. The communication signals and the sending of the information that has been gathered, has been powered by a solar battery in Vanguard.

Senator STENNIS. That just keeps on going?

Mr. HYATT. Yes, sir. The Vanguard pioneered solar batteries.

TIMING OF RETURN TRIP TO MARS

Senator STENNIS. You gentlemen referred earlier to a landing on Mars, with a return trip 3 or 4 months later. Did I hear that correctly?

Mr. TISCHLER. I think I can explain why that must be.

Senator STENNIS. All right.

Mr. TISCHLER. The Earth and Mars revolve around the Sun.

Senator STENNIS. They later mentioned the Moon, as I remember it.

Mr. TISCHLER. Yes.

Senator STENNIS. Go ahead.

Mr. TISCHLER. Quite obviously there are opportune times for making a trip of limited duration from Earth to Mars, but unfortunately as soon as you have arrived at Mars you are not in good position to make a return trip to Earth, so this involves a waiting period until Earth and Mars get into a good position to make the return trip.

Senator STENNIS. So you would have to wait around to come back, whether you could get out and walk around or not, is that right?

Mr. TISCHLER. It is almost that. There is a way of overcoming this difficulty, but it does require what we call excess propulsion, or excess energy.

Senator STENNIS. I was not asking that question in jest; I see you have a problem there. Even if it should not be habitable, you couldn't just return immediately?

Mr. TISCHLER. No.

Mr. HYATT. That is right.

Senator STENNIS. There would be the problem, too, of having control over your vehicle.

Mr. TISCHLER. Beyond any question.

Senator STENNIS. Starting it off again.

Mr. TISCHLER. It is necessary to have absolute and complete control and maneuverability of these devices.

Mr. HYATT. That is right, Senator. Every time we go to a planet or to the Moon proposing to land there and bring someone back or something back, most often we talk about a soft landing; so you have to provide power to land it softly, and after you land it, then you have to provide power to take it off again.

Senator STENNIS. Yes. That is all anticipated, of course, but it is not a separate system, just a brake.

POSSIBILITY OF RETURN TRIP TO MOON BY NOVA VEHICLE

Mr. HYATT. Mr. Tischler showed a chart of the Nova vehicle in his presentation. It is the first vehicle that we are thinking about that could take off the ground, go to the Moon, make a soft landing, and then have enough power to take off from the Moon; to come back and make a soft landing on the Earth. We would start out with 4,800,000 pounds. When we came back we would come back with 2,100 pounds. All the rest of it would be used up in various stages of this trip.

Senator STENNIS. 2,100 pounds of thrust or fuel?

Mr. TISCHLER. 2,100 pounds other than fuel for the actual return to earth.

Mr. HYATT. That is how much that whole thing would weigh when we started off from the ground, 4,800,000; 2,100 pounds would be re-

turned to earth, the rest of it would be used up in the various portions of the trip, it would be thrown away or used up.

Mr. TISCHLER. It would require six or possibly seven stages of propulsion, six of which would be discarded along the way.

Senator STENNIS. Well, you are talking about a thrust of 6 million pounds.

Mr. TISCHLER. Yes. This is the thrust, the force developed by these engines, and this is the actual weight of the vehicle. The thrust is in excess of the weight to lift it off the ground.

Senator STENNIS. Yes.

I have a few more questions here, if we may go back to them. Mr. Lehrer will ask them.

GLOSSARY OF TECHNICAL TERMS REQUESTED FROM NASA

Mr. LEHRER. First, Mr. Hyatt, I believe it would be very helpful in making this record of the greatest use to the average reader if you would provide for the record a glossary covering the technical terms used by the various experts. There were such things as ion propulsion, et cetera.

Mr. HYATT. I will look into it.

(The following information was subsequently provided by NASA:)

The National Aeronautics and Space Administration is presently engaged in preparing a glossary of technical and scientific terms that are in current use in the field of space and astronautics.

Due to the necessity of rather extensive coverage of terms, considerable staff work is being required. Regrettably, the glossary is not available to meet the committee schedule for legislative matters.

ION ROCKET ENGINE AREA OF USE

Mr. LEHRER. Now, Mr. Childs spoke of the electric rockets and discussed in some detail the development of the ion rocket engine. Will this engine work only in outer space, or could it be used within the atmosphere?

Mr. HYATT. It could not be used within the atmosphere, only in outer space.

Mr. LEHRER. Will you explain why?

Mr. HYATT. You want us to explain it now?

Mr. LEHRER. If that is not feasible, will you provide an explanation for the record?

Mr. HYATT. We will provide an explanation for the record.

(The following information was subsequently provided by NASA:)

An ion rocket is a type of electric rocket in which ions and electrons are separated and then ejected in two different beams into a common propulsive jet.

Electric rockets use electric power to produce the jet. The propellant may be either heated electrically to produce high jet velocities, or it may be ionized (electrons separated from the atoms) and accelerated rearward by combinations of electric and magnetic fields acting on the ionized propellant. Jet velocities are not limited by energy available (as in chemical rockets) nor by internal temperatures (as in nuclear rockets); however, the weight of the powerplant required to produce the required electric power effectively limits jet velocity to values in the range of 60,000 to 600,000 miles per hour for space missions of interest.

Electric rockets do not appear feasible for propulsion within the earth's atmosphere for the following reason: It appears that a thrust of the order of 0.0001 times the weight of the powerplant will be the limit obtainable with nu-

clear turboelectric powerplants. This estimate is based on extrapolations of current technology. Such a low thrust can be used quite effectively for propulsion outside the earth's atmosphere; however, ion thrust would be of no practical use within the earth's atmosphere since it would not exceed the retarding force due to resistance of the atmosphere to a moving vehicle.

Senator STENNIS. Continue, Mr. Lehrer.

FEASIBILITY OF FITTING SCOUT VEHICLE WITH WARHEAD

Mr. LEHRER. Mr. Stoney said that the Scout could be fitted with a warhead. Is this merely a theoretical consideration, or is this being given practical consideration by the Department of Defense?

Mr. HYATT. To my knowledge it is not being given practical consideration. I don't think he meant warhead in the sense of an actual definition of the word "warhead." I actually think he meant payload instead of warhead.

Mr. TISCHLER. I don't believe either that he meant warhead as such.

Mr. LEHRER. All right, in the event there is any confusion in the record, it would be desirable to clarify that.

Mr. HYATT. Yes.

ROLE OF NATIONAL AERONAUTICS AND SPACE COUNCIL IN APPROVING PROJECT VEGA

Mr. LEHRER. Mr. Rosen, in talking about Project Vega, mentioned presenting a national space vehicle program which included Project Vega to the Space Council. Has that program been approved and if so, by whom?

Mr. HYATT. It is our understanding that that program has been approved by the Space Council and the President.

Mr. LEHRER. Would you supply for the record a statement indicating when that program was approved by the President or the Space Council?

(The following information was subsequently provided by NASA:)

As has been previously testified to by the Administrator of the National Aeronautics and Space Administration, the information required to answer this question falls within the executive privilege; consequently, it cannot be supplied as requested.

USE OF STORABLE PROPELLANTS IN PROJECT VEGA

Mr. LEHRER. Also, in connection with discussion of the Project Vega, mention was made of the use of storable propellants for the third stage. Are these storable propellants already developed?

Mr. HYATT. The propellants, yes. The engine for them is now under development.

Mr. LEHRER. These are storable liquid propellants?

Mr. HYATT. Yes, sir.

Mr. LEHRER. If these propellants are already developed, are they of the type that could be used in either Atlas or Titan ballistic missiles?

Mr. HYATT. Yes. In fact, those engines are now being developed to use storable propellants.

Mr. LEHRER. You mean the Atlas and Titan engines?

Mr. HYATT. This is an Air Force program. It is not a very emphatic program in the sense that they place a very high priority time limit on it, but it is going ahead.

Mr. LEHRER. If security considerations would permit, could you give us an estimate of when the engines would be available to utilize storable propellants for ICBM purposes, as well as for Vega?

Mr. HYATT. For ICBM, I don't know, I can't answer that question. However, for Vega, the third stage is now under development by JPL and should be ready, at least we anticipate it will be ready, sometime in the fall of 1960. This is a small engine. It is not a big engine like the Atlas.

Mr. LEHRER. In other words, the fact that the engine to use storable propellants will be available for Vega does not mean that it is available for military use because of the difference in size of the engine?

Mr. HYATT. Size of the engine, that is right.

PROJECT VEGA AS SUCCESSOR TO PROJECT MERCURY

Mr. LEHRER. Mr. Rosen mentioned the use of Vega as a successor to Project Mercury, the man-in-space program. There has been testimony before another subcommittee of the Space Committee to the effect that the Department of Defense would be responsible for the follow-on to the present man-in-space program. Do you have any comment to make on this?

Mr. HYATT. I cannot comment on this at this time.

Mr. LEHRER. Would you provide for the record a statement indicating whether Mr. Rosen's statement was correct, or if not, what other qualifications should pertain?

(The following information was subsequently provided by NASA:)

There is one very important use of Vega. It will be used as a successor to the present carrier for Project Mercury, the man-in-space project. Vega will be able to put sufficient payload into a low orbit around the earth, such as a two-man capsule and sustain it for a week or two. The occupants of the capsule would make observations in outer space and perform important scientific work.

Mr. Rosen's statement referred to the capability of Vega as a manned space-vehicle booster and in that context his statement is correct. This capability is being explored by NASA, but program plans for this use of the vehicle have not as yet been formulated.

PRACTICALITY OF MANNED MISSION TO MARS

Mr. LEHRER. I think one final question should be answered. In the discussion of space propulsion requirements, sending an eight-man mission to Mars was used as an illustration. What would be the practical significance or the payoff of a successful mission of that sort?

Mr. HYATT. Well, we can only conjecture, but the first objective in any of these space missions is space exploration, to get the knowledge, the new knowledge that no one can anticipate, and so if and when the time comes to send people up there, they would go there to take measurements, learn all about Mars, and get that information back to us.

Mr. LEHRER. Again, if you would desire, we would appreciate having submitted for the record any more comprehensive explanation of the practical utility of such an expedition.

(The following information was subsequently provided by NASA:)

An eight-man Mars expedition is used in some of the NASA congressional presentations to illustrate the large weight benefits to be derived from developing nonchemical propulsion system (nuclear rockets and electric rockets) for advanced space missions. This mission is typical of the well-provisioned, well-manned expeditions that will be desirable in the future to carry out thorough explorations of the near planets. There appears to be no basic reason why such expeditions will not eventually become feasible, but our knowledge of the environment of interplanetary space (meteoroid distribution and intensity, radiation intensity) is as yet too meager to state just how difficult the job will be. Analyses from the standpoint of propulsion requirements, however, show that with foreseeable extensions of current technology and total weight that must be launched into a close orbit around the earth to get such an expedition underway will be in the range of 300,000 to 500,000 pounds. Launching rockets capable of placing such weights into orbit with three or four launchings should be available in the late 1960's or early 1970's. Whether electric or nuclear rockets needed for the remainder of the mission will be available near that time depends largely on the magnitude of the effort in research and development that is supported during the next 10 years. During this period, also, the environment of the planets and interplanetary space will be under intensive study with scientific probes, so that we can gradually acquire a more precise understanding of the magnitude of the undertaking. In short, we see no fundamental obstacle to practical realization of such missions within the next 10 to 20 years but we know that a great deal of research and development work in a wide variety of fields is necessary before a definite time for such missions can be precisely estimated.

Mr. LEHRER. That completes the questioning of the staff.

OTHER RELATED GOVERNMENT PROGRAMS

Senator STENNIS. Yes. Let me ask this, gentlemen; for information. These projects you have been talking about this afternoon are up on the front line—they are our forward steps in this field. Now, is anyone else carrying on similar projects? I know the explanation was made here about atomic energy programs and your cooperation with them, but are similar projects now being carried on by anyone else within the Government?

Mr. HYATT. No, sir, not for any one of the particular vehicles we have described. They may be under the cognizance of different agencies but there are no duplicates in the specific kinds of vehicles. ARPA, for example, does not have another Vega vehicle.

Senator STENNIS. Yes.

Mr. HYATT. On the other hand, they have the next generation which is that 1½-million-pound cluster that is being developed by the Army, by Dr. von Braun's group, for them. So this is another step, but I don't know of any duplicating vehicles in any other agency.

Senator STENNIS. Well, now, this million-and-a-half pound thrust Dr. von Braun is developing—what do you call this one?

Mr. HYATT. This is a single chamber. This is just one engine. In order to get his million-and-a-half-pound thrust he uses eight engines.

Senator STENNIS. Clustered?

Mr. HYATT. All clustered together.

Senator STENNIS. Well, maybe it is repetition, but what is the advantage of this one over the cluster idea?

Hr. HYATT. Well, the cluster, if we want to use, say, 6 million pounds, then we would have to have 4 times 8 or 32 engines. This gets a little difficult and probably not reliable.

Senator STENNIS. You don't think it would be feasible to build it up that high?

Mr. HYATT. I wouldn't think so.

Senator STENNIS. Is that your answer?

Mr. HYATT. That is my answer, I don't think it would be practicable. The reliability would go down too far.

Mr. TISCHLER. I think I might add to that there can be no denying that the million-and-a-half-pound single chamber engine will have a greater capability than the million-and-a-half-pound cluster engine, because it is a better engine for its purpose, designed with an advanced state of art, a lighter engine, and so forth. However, in order to meet a requirement for a million-and-a-half-pounds of thrust in a vehicle at an early date, the Department of Defense is going ahead with this cluster engine using engines now in existence. There is no doubt we will have a vehicle available at a much earlier date than a vehicle using this single-chamber engine could be made available.

Senator STENNIS. It is not the ideal way of doing it; is it the most practical way of doing it?

Mr. TISCHLER. It is the quick way of doing it.

Mr. HYATT. We don't intend to build a competing vehicle with the Army Ballistic Missile Agency.

Senator STENNIS. You didn't say anything about recordings and telemetry, and all of those problems. Of course, you would use that as an auxiliary here, but they are not involved in this——

Mr. HYATT. That is right. This is the propulsion technology. The other will be discussed at a later time by a different group.

Senator STENNIS. Well, I am impressed with the subjects, the arrangements, and all of the witnesses that you and Mr. Lehrer have worked on. I don't understand all the technical things said here, but it certainly was helpful and interesting, and I think it would be helpful to the public, to the entire committee and to the Congress.

Do you gentlemen have anything else to say before we recess?

Mr. HYATT. No, sir. We have enjoyed it very much.

Senator STENNIS. I have enjoyed this immensely, gentlemen, and the thanks of the subcommittee go to each one of you. We will take a recess now until 10:30 tomorrow morning.

(Whereupon, at 6 p.m., the subcommittee adjourned, to reconvene at 10:30 a.m., Wednesday, April 8, 1959.)

NASA AUTHORIZATION FOR FISCAL YEAR 1960

WEDNESDAY, APRIL 8, 1959

U.S. SENATE,
NASA AUTHORIZATION SUBCOMMITTEE OF THE
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10:40 a. m., in room 224, Old Senate Office Building, Senator John Stennis presiding.

Present: Senators Stennis, Young of Ohio, Dodd, Cannon, Smith, and Martin.

Also present: Max Lehrer, assistant staff director; Dr. Glen P. Wilson, chief clerk; and Dr. Earl W. Lindveit, assistant chief clerk.

Senator STENNIS. The subcommittee will come to order, please. I want to indulge the Chair just a minute for an informal statement. The presentation yesterday afternoon, getting down into details of some of these marvelous programs, was very interesting and helpful to the subcommittee. I think that the information is very timely and will be of interest to the American people. I was surprised that much of it was unclassified. I think it is appropriate that the press is taking notice of these programs as they are developing here and that the American people will be informed of them. I was impressed, as the other members of the subcommittee were, with the young men who appeared here yesterday afternoon, and with their apparent dedication to their work. We look with favor on coming into contact with all of you different gentlemen who work behind the doors, so to speak, at NASA; those we had yesterday afternoon and those we have listed here for today and tomorrow.

By the way, we hope you will have some better and more convenient quarters in due course of time, too. We passed a little bill yesterday that has that in view. So even though you deal in space, I think you have your feet on the ground, based on the evidence yesterday and we are looking forward to hearing more today.

Members of the committee, we have here Dr. Homer E. Newell, Jr., Assistant Director of Space Sciences, who is going to give us a special word now. Are you going to emphasize something on the atmosphere? What is your special assignment, Doctor?

Dr. NEWELL. My special assignment this morning is to talk on atmospheres and then introduce some of the fellows who are going to talk on the rest of space science.

Senator STENNIS. This is an open hearing. Proceed, Doctor.

Dr. NEWELL. A short while ago I had the privilege of appearing before your committee to give a broad paintbrush picture of the sciences program. Today we feel privileged to come back and give you some of the details in separate areas in the space sciences program.

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Senator STENNIS. Pardon me just a minute. Yesterday we followed the general practice of you presenting your witnesses, three or four or whatever number it was, then we would ask questions. Another item, it is the policy of this subcommittee that testimony be under oath, so you and such others who are expected to testify this morning, would you stand, please? Do you and each of you solemnly swear that your testimony here before this committee will be the truth, the whole truth, and nothing but the truth, so help you God?

Dr. NEWELL. I do.

Dr. CLARK. I do.

Dr. MEREDITH. I do.

Dr. FELLOWS. I do.

Dr. O'KEEFE. I do.

Mr. STOLLER. I do.

Mr. CROCKER. I do.

(The biographical sketches of the witnesses follow:)

HOMER E. NEWELL, JR., ASSISTANT DIRECTOR FOR SPACE SCIENCES, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Homer E. Newell, Jr., joined the staff of the National Aeronautics and Space Administration as Assistant Director for Space Sciences on October 20, 1958. Previously, at the U.S. Naval Research Laboratory he was Acting Superintendent of the Atmosphere and Astrophysics Division and also science program coordinator for Project Vanguard, the U.S. scientific earth satellite program.

A native of Holyoke, Mass., Dr. Newell earned both his bachelor and master of arts degrees from Harvard University, and his Ph. D. in mathematics degree from the University of Wisconsin in 1940.

From 1940 to 1944 he was an instructor and later assistant professor at the University of Maryland, and a ground instructor in navigation with the Civil Aeronautics Administration from 1942 to 1943.

Dr. Newell joined the Naval Research Laboratory in 1944, and became Head of the Rocket Sonde Branch in 1947. In this position, he was in charge of the upper atmosphere research program of NRL. In 1955 he was named Acting Superintendent of the Atmosphere and Astrophysics Division.

His scientific committee memberships have included the Special Subcommittee on the Upper Atmosphere of the National Advisory Committee for Aeronautics (1947–51), and the Rocket and Satellite Research Panel (formerly Upper Atmosphere Rocket Research Panel) since 1947. He is currently Chairman of the Rocket and Satellite Research Panel.

Dr. Newell is the author of several technical books and numerous articles. He is a member of Phi Beta Kappa, Research Society of America, the American Geophysical Union, the American Rocket Society, and he is a fellow of the American Association for the Advancement of Science.

Dr. Newell, his wife, and their four children live at 4401 Westbrook Lane, Kensington, Md.

JOHN F. CLARK, CHIEF, PLANETARY SCIENCES PROGRAMS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John F. Clark, Chief of Planetary Sciences Programs in the Office of the Assistant Director for Space Sciences, joined the headquarters staff of the National Aeronautics and Space Administration in October 1958. Previously he was Head of the Atmospheric Electricity Branch of the U.S. Naval Research Laboratory.

A native of Pennsylvania, Dr. Clark earned a bachelor of science degree in electrical engineering from Lehigh University in 1942; a master of science in mathematics from George Washington University in 1946; a professional electrical engineer's degree from Lehigh in 1947; and a doctor's degree in physics from the University of Maryland in 1956.

From 1942 to 1947, Dr. Clark was an electronics engineer at the Naval Research Laboratory. After 1 year as an assistant professor of electrical engineering at

Lehigh University, he rejoined the NRL staff as a physicist. He remained at NRL until he was appointed to the NASA staff. During his scientific career, he has specialized in ionospheric and atmospheric physics, especially atmospheric electricity.

Dr. Clark is a member of Phi Beta Kappa, Sigma Xi, Tau Beta Pi, Sigma Pi Sigma, and the Scientific Research Society of America. He is also a member of the American Geophysical Union, the American Institute of Physics, the American Association of Physics Teachers, and the Institute of Radio Engineers.

Dr. and Mrs. Clark (the former Virginia A. Bell) and their two children live at 9604 Garwood Street, Silver Spring, Md.

LESLIE H. MEREDITH, HEAD, FIELDS AND PARTICLES BRANCH, SPACE SCIENCES DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Leslie H. (Hugh) Meredith joined the National Aeronautics and Space Administration as head of the Fields and Particles Branch, Space Sciences Division on January 1, 1959. Previously he was head of the Rocket Sonde Branch at the U.S. Naval Research Laboratory. During his career he has specialized in research in the fields of cosmic ray and auroral particles, night-sky radiation, and magnetic fields.

Dr. Meredith attended the State University of Iowa where he was awarded a bachelor of arts degree in 1950, master of science in 1952, and Ph. D. in 1954. While at the university he designed and built experimental equipment for balloon and rocket flights.

After joining the staff of the Naval Research Laboratory in 1954, Dr. Meredith was named head of the Meteors and Aurora Section, Rocket Sonde Branch. He planned, organized, and directed programs in the fields of meteors, auroral particles, earth's magnetic field, night airglow, and earth photography. He was appointed Branch head in October, 1958.

Dr. Meredith is a member of the American Physical Society, the American Geophysical Union, Sigma Xi, and Phi Beta Kappa.

Dr. and Mrs. Meredith (the former Marilyn Church) and their three children live at 105 Pine Grove Circle, Alexandria, Va.

ROBERT F. FELLOWS, HEAD, CHEMICAL AERONOMY PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Robert F. Fellows joined the National Aeronautics and Space Administratoin as head of the Chemical Aeronomy Program in the Office of the Assistant Director for Space Sciences on January 26, 1959. Previously he was head of the Analytical Laboratory of Sprague Electric Co.

Born in Cleveland, Ohio, in 1920, Dr. Fellows earned a bachelor of science degree in chemistry at Baldwin-Wallace College in 1943. He was awarded his Ph. D. in physical chemistry from Brown University in 1951.

After graduation from college, Dr. Fellows joined the staff of Williams College as instructor in chemistry from 1943 to 1944. During the following 2 years he served as an officer in the U.S. Navy.

Dr. Fellows joined the Dow Chemical Co. in 1951 as a physical chemist in the spectroscopy laboratory. In 1953 he became a member of the staff of the Sprague Electric Co., North Adams, Mass.

Dr. Fellows has specialized in research in dielectric phenomena, spectrographic instrumentation, and chemical analysis. He is a member of the American Chemical Society, the New England Spectrographic Society, the Instrument Society of America, and Sigma Xi.

Dr. and Mrs. Fellows (the former Helen Heeter) have three children. The family, currently living at 31 Glen Street, Williamstown, Mass., will move to the Washington area in the near future.

JOHN A. O'KEEFE, ASSISTANT CHIEF, THEORETICAL DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John A. O'Keefe, Assistant Chief of the Theoretical Division, joined the National Aeronautics and Space Administration in November 1958. Previously he

was Chief of Research and Analysis in the Geodetic Division of the U.S. Army Map Service.

Dr. O'Keefe was born in Lynn, Mass. in 1916. He earned a bachelor of arts degree from Harvard College in 1937, specializing in astronomy, mathematics, and physics. After graduate study at Harvard University he earned his Ph. D. at the University of Chicago in 1941.

After a year as professor of mathematics and astronomy at Brenau College, Gainesville, Ga., he joined the staff of the U.S. Lake Survey as associate mathematician and engineer. In 1944, the Lake Survey was transferred to the Army Map Service, where Dr. O'Keefe remained until his appointment to the NASA staff.

In addition to being Chief of Research and Analysis in the Geodetic Division, Dr. O'Keefe was technical advisor to the Army Map Section of Project Vanguard. His research has included the mathematical and physical problems in intercontinental distances in the size of the earth.

Dr. O'Keefe lives at 3712 Thornapple Street, Chevy Chase, Md.

MORTON J. STOLLER, CHIEF, SPACE SCIENCES PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Morton J. Stoller was appointed Chief of the Space Sciences Program, in the Office of the Assistant Director for Space Sciences at NASA headquarters, shortly after the National Aeronautics and Space Administration was established on October 1, 1958. He is recognized as an authority on all phases of instrument research and development work.

Stoller is a native of New York. He earned a bachelor of science degree in electrical engineering from the College of the city of New York in 1938. He was awarded a master's degree in electrical engineering from the University of Virginia in 1952.

Stoller joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1939, as an electrical engineer at the Langley Aeronautical Laboratory. In 1947 he was named Assistant Chief of the Instrument Research Division at Langley.

His research work has chiefly been concerned with the instrumentation used to obtain data from pilotless aircraft. He has also performed research in telemetering and computing.

Stoller is a member of the American Institute of Electrical Engineers.

J. ALLEN CROCKER, CHIEF, GUIDANCE AND CONTROL PROGRAMS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

J. Allen Crocker, as Chief of Guidance and Control Programs in the Office of the Assistant Director for Advanced Technology, National Aeronautics and Space Administration, is responsible for space vehicle components regarding guidance, control, and stability. He joined the NASA in November 1958; previously he was Assistant Technical Director at headquarters of the U.S. Air Force, Office for Atomic Energy.

Born in Elmira, N.Y., in 1911, Crocker earned a bachelor of science degree in engineering from George Washington University in 1933.

From 1936 to 1942, Crocker was engaged in physical and chemical research at the Carnegie Institution of Washington, D.C. He was an engineer, from 1942 to 1945, with the Manhattan project, the forerunner of the Atomic Energy Commission.

Self-employed from 1945 to 1948, he was engaged in contract work with Government and industry for the production of technical display models. From 1948 until his appointment to the NASA staff, he was a member of the Air Force's Office for Atomic Energy.

Crocker has specialized in research in geophysics and electromechanical devices. He is a member of the American Institute of Electrical Engineers, the American Association for the Advancement of Science, and is a registered professional engineer in the District of Columbia. During the past 5 years, he twice received the Exceptional Civilian Service Award from the U.S. Air Force.

Mr. and Mrs. Crocker (the former Margaret Cuppy) and their five children live at 9327 East Parkhill Drive, Bethesda, Md.

Senator STENNIS. Proceed.

TESTIMONY OF DR. HOMER E. NEWELL, JR., ASSISTANT DIRECTOR FOR SPACE SCIENCES, NASA

Dr. NEWELL. Scientists have been interested in the upper atmosphere and space for a long, long time. This earliest of sciences goes back in history for hundreds and thousands of years. However, the tools that were available for research centuries ago were not as powerful as those we have today. As far as I have been able to learn, the first attempt at direct exploration of the upper atmosphere occurred in 1749 when Dr. Wilson F. Glasgow sent up a kite. From the use of a kite man went to balloons, and later manned balloons. Free balloons are now used extensively in weather observations. Aircraft and giant balloons have also been used. Now we have rockets which can be used for space probes, for the launching of satellites, and for the sounding of the atmosphere.

Today, the men who are with me want to review for you the program we visualize and have set up in studying the earth's upper atmosphere and outer space. I might point out that prior to the establishment of NASA, there had been a rather extensive program of sounding of the upper atmosphere in this country. The United States fired some 400 sounding rockets before the International Geophysical Year. During the 1½ years of the Geophysical Year another 200 have been launched and, of course, we also launched our first earth satellites and space probes. With these tools we plan and we intend to continue to investigate the upper atmospheres as one particular subject. First, I would like to tell you that we intentionally put an "s" on the word "atmosphere" because we are thinking not only of the earth's atmosphere, but, also, the atmosphere of the sun, the atmosphere of the planets, and the atmosphere of the moon if there turns out to be any.

One of our major interests in the atmospheres of the planets is to get a look at different types of atmospheres so that when we come back in a broader perspective to view the earth's atmosphere, we may see things that we did not see before.

THE EARTH'S ATMOSPHERE

In this first chart I would like to review for you some of the things we know about our atmosphere as a basis for pointing up the things we don't know and want to study.

To begin with, it is customary to measure the pressure of the atmosphere, that is the force with which it pushes down on all things submersed in it, in terms of atmospheres. The sea level pressure of our atmosphere is one atmosphere. It is actually equivalent to a force of 1 ton on a square foot of area, a square foot being a square 1 foot on the side. Since the average human being has about 20 square feet of area, this means that each person here in this room is subject to about 20 tons of force due to the earth's atmosphere.

However, when we go up to 50 or 60 miles altitude, the atmosphere has fallen off in pressure to one one-millionth of what it was at sea

level, and if we go up to 100 miles the pressure has decreased to one one-billionth of what it is at sea level. So you see the atmosphere is thinning out, not just gradually, but quite rapidly as we go up in altitude.

At 200 miles our measurements indicate that we have only one ten-billionth of what we have at the surface of the earth. I would like, at this moment, to insert that this doesn't mean that this is unimportant to us even from a practical point of view, because it is in this region of the atmosphere, as one of the speakers to follow will tell you, that the ionosphere exists. This is the portion of the atmosphere which is electrified and which makes it possible for us to send radio waves around the world.

Now another thing, this curve represents the temperature of our atmosphere. At one time it had been thought that after the first decline in temperature which we observe as we climb mountains or as we go up in aircraft, that the temperature remains constant at about minus 70° C. But it turns out that this is not correct. The atmosphere warms up again, then cools off again, then warms up to the extremely high temperatures you see here, 2,000° to 3,000° F. This means, then, that the individual air molecules are moving about at terrific speeds and individually carry large energies in comparison with what the molecules near the ground carry. However, it does not means that if you put a potato out here it would cook rapidly.

The reason is this: the atmosphere has thinned out so much that there aren't enough molecules to deliver sufficient heat to the potato to cook it. Rather, the potato would cool off because of the fact that it would radiate its energy, except for the side that faces the sun. The sun would heat and roast this side.

We know that the composition of the atmosphere at the surface of the earth includes nitrogen, oxygen molecules, about nine-tenths of a percent of argon, some ozone, but not very much, and carbon dioxide. Water vapor is also present and is important as it is the major active element in our weather processes. Water vapor is highly variable. On the average it amounts to about three-tenths of 1 percent. Its maximum amount is about 2 percent.

As we go up in altitude there is not much change in nitrogen. But in the case of oxygen, a change does occur up here at 60, 70, or 80 miles. The oxygen begins to dissociate, that is to say, molecules separate into two single atoms so that at these altitudes we find atoms of oxygen instead of molecules. This is due to the effect of the sun's radiation on the upper atmosphere. Ozone is formed and reaches a maximum at 20 miles or so. The ozone molecule consists of three atoms of oxygen. It is highly lethal. In fact, seven parts per million is deadly. Up here at this altitude one finds about seven parts per million. Carbon dioxide and argon have decreased considerably, and so does water vapor.

Now we get to a region here which is called the region of diffusive separation. This is just a technical way of saying it is a region in which the lighter gases drift upward and the heavier gases settle down. A common example of this is the way cream drifts upward in unhomogenized milk, and the heavier milk settles out. Thus we expect at the top of the atmosphere to find hydrogen, and down in this portion more argon relative to, say, nitrogen than one would normally find in a well-mixed atmosphere.

You may wonder why it is that diffusive separation occurs here and not lower down. The answer is our weather, the mixing, stirring, turbulent motions of the atmosphere keep things uniform down here. When we get up here this no longer exists.

Now as to things we don't know, we don't know whether there is hydrogen up there, and we would like to find out. We will look for it. In particular, we are interested in whether or not the hydrogen joins in with a hydrogen atmosphere of the sun. We don't understand the weather of the upper atmosphere. We are interested in learning about the effects of the sun, the effects of geographic position and season, the nature of the winds, and so forth, for the upper atmosphere.

Now moving from this description of our atmosphere, let us consider how we make measurements of these things. This complicated looking thing is the mass spectrometer for the measurement of gas composition.

Before I take up the description of this, let me mention that when we began the study of the earth's upper atmosphere by using V–2 rockets right after the end of the last war, one of the first problems was to measure the variation of pressure with altitude. We had a V–2 assigned to us by the Army. It had a rigidly fixed date because of the launching problem. We didn't have any special equipment ready. The question was how to swing into action and make this pressure measurement quickly. The answer was very simple. The researcher who had this assignment simply took a small electric light bulb, knocked the top off of it, and then calibrated the base and filament as a pressure gage. The principle here was that the more atmosphere, the more rapidly the air cooled the filament of the light bulb. The less atmosphere, the less cooling, and, therefore, the higher the temperature of the filament.

The higher the temperature of the filament, the more resistance in it. The resistance could be measured in the rocket and radioed back to the ground. Thus, by measuring the varying electrical resistance of this modified light bulb at each altitude, we got our first measurements of pressure in the upper atmosphere.

From that first start to the present day, instrumentation has become more and more complicated. We now have instruments like this one which is capable of determining the different constituents in the atmosphere.

In this case what happens is that the atmospheric gases near the rocket are brought into the instrument. They are bombarded by electrons from a hot filament. This causes the atmospheric gases to become charged. Now charged particles moving in a magnetic field move in a curved path. The magnetic field causes the charged particles to deflect. In fact, it is this property that is used in TV tubes now for focusing the beam from the electron gun which makes your picture on the TV tube.

By varying the intensity of the magnetic field one can pick out which particle will be brought back to the detector. With such an instrument one can record a series of peaks corresponding to the individual constituents of the atmosphere. In a rocket, of course, this measurement has to be made automatically, put into a telemetering or radio transmitter, and sent to ground where it is received. A recorder then transcribes the data into a record like this one.

This is only one of many types of instruments that are used for this sort of work.

THE ATMOSPHERE OF VENUS

Let us look beyond the earth's atmosphere out to the other planets and see what we have. For comparison with the Earth we have Venus. Note that the diameters are roughly the same. This is the reason that Venus is often called the twin planet to the Earth. The surface gravity on Venus is about 85 percent of that of the Earth. The temperature of the surface of Venus, however, is unknown. Measurements in the heat wavelengths, the infrared region, indicate the temperature of Venus to be about 110° F. This is of the order of what we experience on the Earth during summer days. On the other hand, radio wave measurements indicate 570° F. We don't know just where this temperature applies, but it may be at the surface of the planet itself. If it does, then it raises serious questions as to whether any life can exist. The average temperature for the Earth is about 60° F.

The atmospheric pressure at the surface of Venus is probably twice as great as that of the Earth because there is more atmosphere on Venus. We don't really know the composition of the atmosphere. We know that there is some carbon dioxide. This is detected by the radiation that it gives off to us. No water vapor has been detected in spite of the fact that the whole surface is covered by intense clouds. Those clouds are probably carbon dioxide. Is there any nitrogen? We don't know. Of course, I have already reviewed the Earth's atmosphere for you.

THE MOON AND MARS

In the case of the Moon and Mars, I should mention that the Moon is not a planet. It is our satellite. However, it is comparable to the planets so we have included it here. The moon is only 2,000 miles in diameter, and Mars has a diameter of 4,000 miles. The surface gravity on the Moon is one-sixth of that on Earth, so a 60-pound child would really weigh only 10 pounds on the Moon. The temperature on the Moon varies from the boiling point of water on the bright side to minus 243° F. on the dark side.

The surface gravity of Mars is about four-tenths that of the Earth. On the surface of Mars the average temperature is probably about minus 15° F.

The Moon as far as we can tell from the surface of the Earth has no atmosphere, but we are interested in whether or not there is an atmosphere of heavier gases close to the surface of the Moon. In the case of Mars, pressure at the surface amounts to about one-tenth of an Earth atmosphere. There is some carbon dioxide and there appears to be a small amount of water vapor. We don't know whether there is any nitrogen.

JUPITER AND SATURN

Jupiter and Saturn are a couple of most interesting planets. Jupiter is by far the largest planet, 86,000 miles in diameter. Saturn comes next, 74,000 miles. The surface gravity of Jupiter is two and a half times that of the Earth, so you would find it rather difficult to walk around on Jupiter if you could get there. The surface gravity of Saturn is slightly more than that of the Earth.

Size doesn't necessarily determine the gravity. The total mass in the object is important in determining this. That is why Saturn, although it is nearly as large as Jupiter, has a considerably lower gravity. The temperature at the surface of minus 240° F. is quite forbidding.

In the case of Saturn, the temperature is even lower. We do not know the atmospheric pressure. This is something we would like to find out. We know that both of these planets have ammonia and methane in their atmospheres, certainly an inhospitable sort of atmosphere. In the case of Jupiter, we suspect that there is a considerable amount of hydrogen and helium. We don't know about nitrogen, oxygen, or water vapor. We have the same questions about Saturn. Of course, we are very much interested in what the rings are.

FUTURE ATMOSPHERES PROGRAM

Our program for the next 2 years will include the following activities. One space probe will measure pressure, density, temperature, and composition of the atmospheres of Venus or Mars. This is probably toward the end of 2 years, maybe 3 years, away, but we have to begin our instrumentation work now.

Measurements of the density and composition of interplanetary spaces and the Moon's atmosphere call for one space probe.

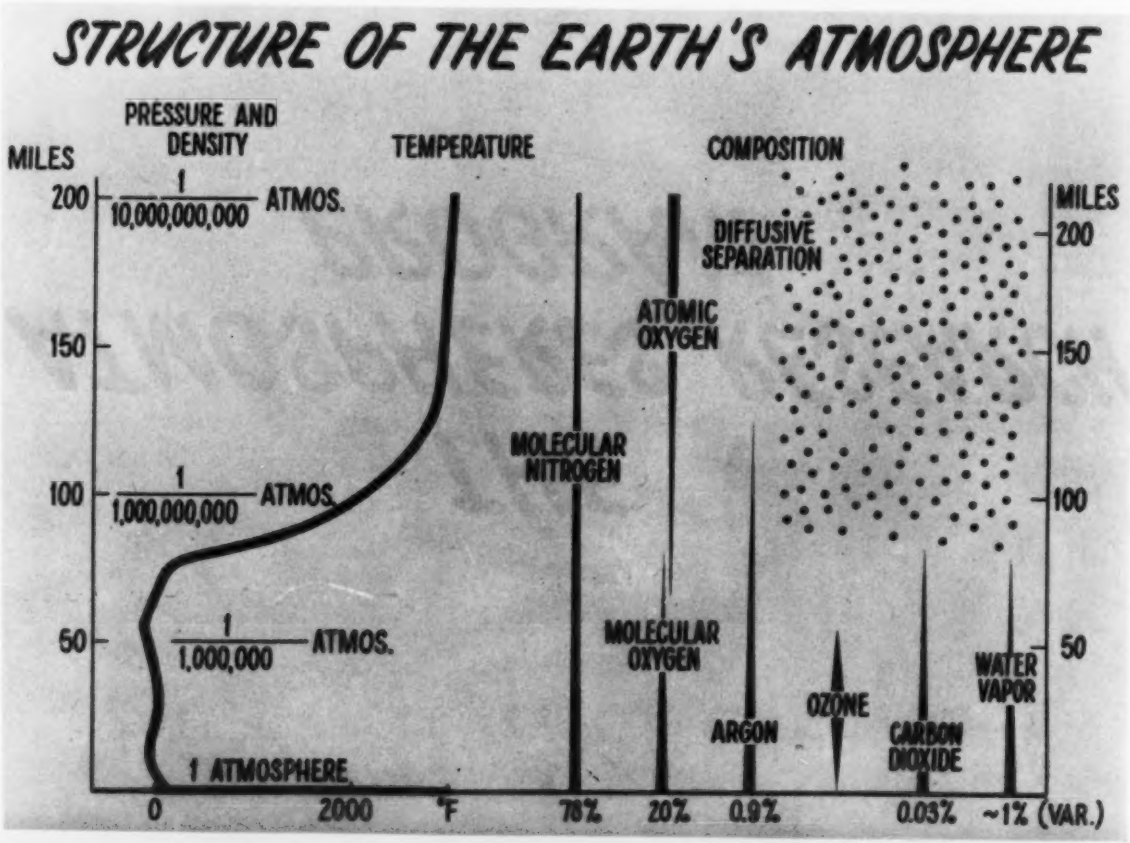
Three satellites will be used to study the Earth's atmosphere, pressure, density, temperature, and composition. Of these three satellites, one is a Vanguard satellite which will be coming up in the near future.

We also have a sounding rocket program. Forty sounding rockets for the rest of this calendar year and about 100 sounding rockets in the next calendar year will be used to measure pressure, temperature, density, composition, and winds in the region between 50 and 100 miles above the Earth's surface.

Also, 40 sounding rockets will be used to measure these same things, but below 50 miles. The purpose here is to develop an extension of weather soundings and observations. You might call this an extended meteorological program using sounding rockets.

This brings me to the end of my portion of the discussion. I would like now to turn to the next man, who is Dr. John F. Clark.

THE ATMOSPHERES RESEARCH PROGRAM


STRUCTURE OF THE EARTH'S ATMOSPHERE
PRESSURE AND DENSITY
TEMPERATURE
COMPOSITION
MILES
200
150
100
50
1/10,000,000,000 ATMOS.
1/1,000,000,000 ATMOS.
1/1,000,000 ATMOS.
1 ATMOSPHERE
0
2000 °F
DIFFUSIVE SEPARATION
ATOMIC OXYGEN
MOLECULAR NITROGEN
MOLECULAR OXYGEN
ARGON
OZONE
CARBON DIOXIDE
WATER VAPOR
78%
20%
0.9%
0.03%
~1% (VAR.)

0
2000
°F
78%
20%
0.9%
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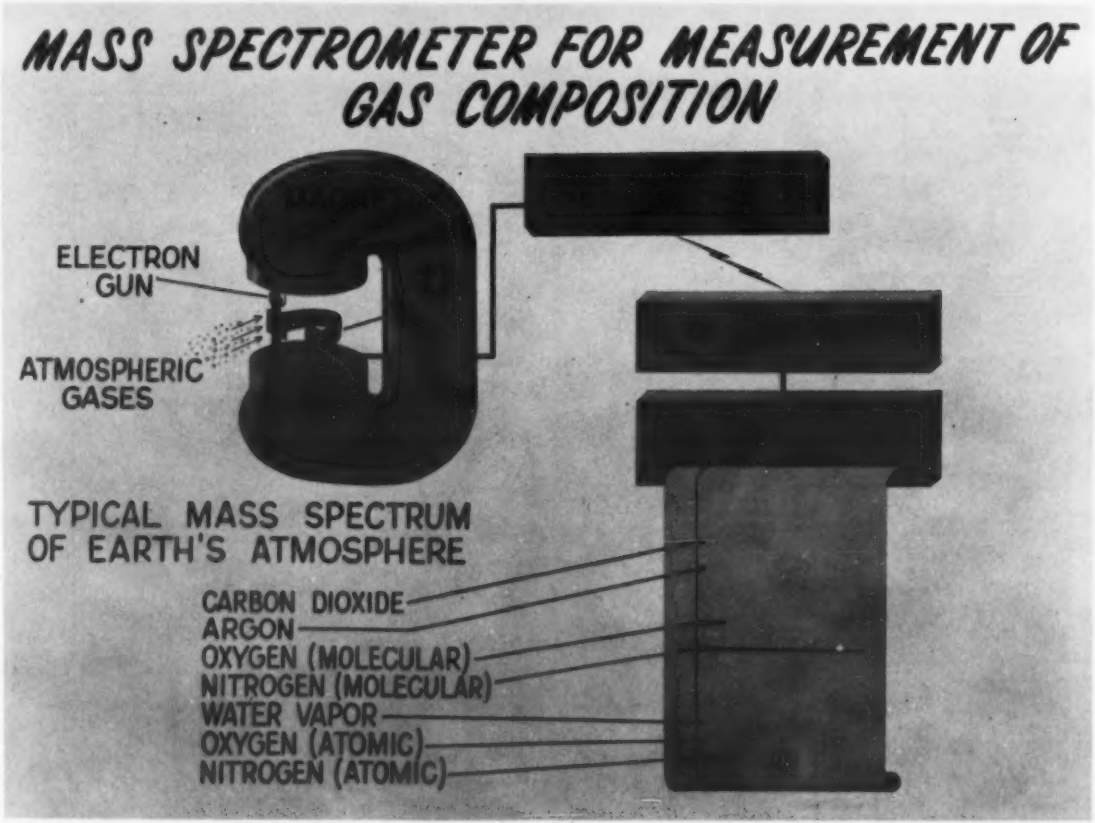
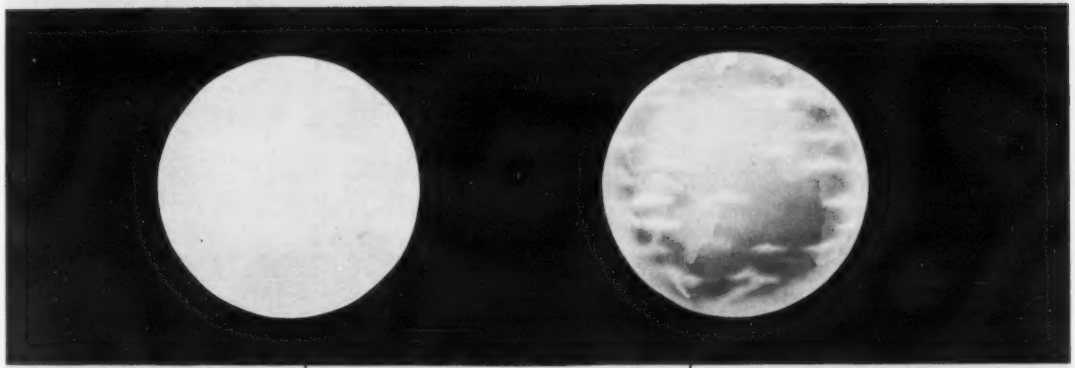

MASS SPECTROMETER FOR MEASUREMENT OF GAS COMPOSITION
ELECTRON GUN
ATMOSPHERIC GASES
TYPICAL MASS SPECTRUM OF EARTH'S ATMOSPHERE
CARBON DIOXIDE
ARGON
OXYGEN (MOLECULAR)
NITROGEN (MOLECULAR)
WATER VAPOR
OXYGEN (ATOMIC)
NITROGEN (ATOMIC)

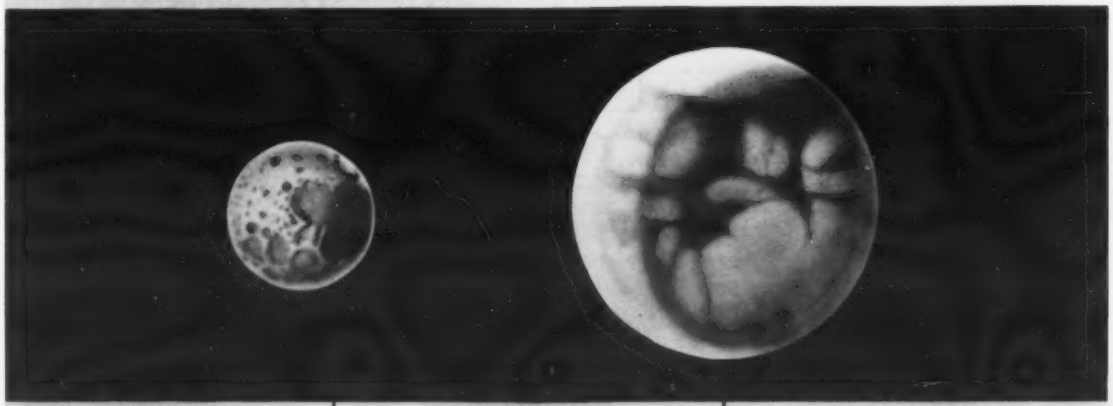
VENUS AND EARTH



PLANET	VENUS	EARTH
DIAMETER	7,800 MILES	7,920 MILES
SURFACE GRAVITY RELATIVE TO EARTH	0.85	1.0
TEMPERATURE	110°F ABOVE CLOUDS (INFRA-RED) 570°F AT SURFACE (RADIO @ 3.15cm)	60°F (SURFACE)
ATMOSPHERIC PRESSURE AT SURFACE	2(?)	1
ATMOSPHERIC COMPOSITION	CARBON DIOXIDE (WATER VAPOR? NITROGEN?)	AIR { NITROGEN, OXYGEN ARGON, CARBON DIOXIDE WATER VAPOR

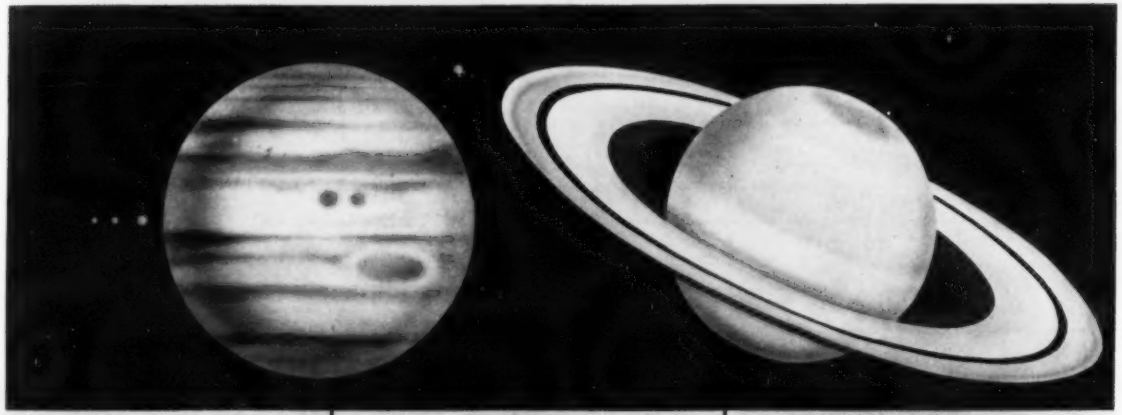
	(WATER VAPOR? NITROGEN?)	WATER VAPOR

MOON AND MARS



PLANET	MOON	MARS
DIAMETER	2,162 MILES	4,215 MILES
SURFACE GRAVITY RELATIVE TO EARTH	0.16	0.38
TEMPERATURE	212°F FULL MOON (SURFACE) -243°F DARK SIDE	-15°F (SURFACE)
ATMOSPHERIC PRESSURE AT SURFACE	ESSENTIALLY ZERO	1/10
ATMOSPHERIC COMPOSITION	?	CARBON DIOXIDE WATER VAPOR (NITROGEN?)

JUPITER AND SATURN



PLANET	JUPITER	SATURN
DIAMETER	86,720 MILES	74,940 MILES
SURFACE GRAVITY RELATIVE TO EARTH	2.64	1.17
TEMPERATURE	-240°F (SURFACE)	-290°F (SURFACE)
ATMOSPHERIC PRESSURE AT SURFACE	?	?
ATMOSPHERIC COMPOSITION	AMMONIA, METHANE [HYDROGEN? NITROGEN? OXYGEN? WATER VAPOR?]	AMMONIA, METHANE HYDROGEN? NITROGEN? OXYGEN? WATER VAPOR?

COMPOSITION | OXYGEN? WATER VAPOR? | OXYGEN? WATER VAPOR?

ATMOSPHERES PROGRAM (2 YEARS)

PURPOSE	LAUNCHINGS
PRESSURE, DENSITY, TEMPERATURE AND COMPOSITION OF THE ATMOSPHERES OF VENUS OR MARS	ONE SPACE PROBE
DENSITY AND COMPOSITION OF INTERPLANETARY SPACE AND THE MOON'S ATMOSPHERE	ONE SPACE PROBE
PRESSURE, DENSITY, TEMPERATURE AND COMPOSITION OF THE EARTH'S ATMOSPHERE ABOVE 100 MILES FROM THE EARTH'S SURFACE	THREE SATELLITES
PRESSURE, TEMPERATURE, DENSITY, COMPOSITION AND WINDS IN THE REGION BETWEEN 50 AND 100 MILES ABOVE THE EARTH'S SURFACE	FORTY SOUNDING ROCKETS
WORLD-WIDE SURVEY OF PRESSURE, DENSITY, TEMPERATURE, COMPOSITION AND WINDS UP TO 50 MILES ABOVE THE EARTH'S SURFACE	FORTY SOUNDING ROCKETS

39621 O—59—pt. 1——10

Senator STENNIS. All right, Dr. Clark, we are glad to have you; and thank you, Dr. Newell. As I said at the beginning, gentlemen, these programs are very interesting. When you get into the involved physics, though, or the chemistry, we can't follow. You can hit us hard with the high points, you see, and just instruct each other on those other points.

TESTIMONY OF DR. JOHN F. CLARK, CHIEF, PLANETARY SCIENCES PROGRAMS, NASA

Dr. CLARK. The earth's ionosphere is the spherical shell of charged atmospheric gases which stretches from 40 miles to many tens of thousands of miles above the earth. This region has been studied intensively since its discovery some four decades ago, because on its vagaries depends the very existence of all shortwave intercontinental radio communications. Today I shall discuss, in order:

Ionospheric knowledge acquired from the earth's surface.
Additional knowledge already gained using spacecraft.
Research objectives of the national ionospheres program.
The long-range ionospheres program approach.
The current ionospheres program, including hardware.
Two-year ionospheres program summary.

THE IONOSPHERE AS SEEN FROM THE EARTH'S SURFACE

The first chart presents the earth's ionosphere as it was pictured before the advent of rockets and satellites. During daylight hours, as seen on the right side of the chart, ultraviolet rays from the sun produce maximum charging or ionization of the atmospheric gases at four particular levels: The D region at from 35 to 50 miles altitude, the E region at 60 miles, the F1 region at 120 miles, and the F2 region at some 180 miles. These charge density distributions vary with latitude, with season, and with activity on the sun. At night, as shown on the left side of the chart, the two F regions merge, the E region becomes patchy or sporadic in nature, and the D region disappears altogether. The arctic and antarctic ionospheres are particularly subject to erratic effects which are related to auroral displays (northern lights). Such disturbed ionospheric conditions are frequently related to ionizing streams of particles which take several days to reach the earth's atmosphere from the sun. Meteors also make a small contribution to the charging or ionization of the atmospheric gases, particularly in the E region.

Much of the importance of the ionosphere centers on its effect on worldwide radio communications. In effect, it is possible to bounce certain radio waves off the lower surface of the ionosphere and back again to earth thousands of miles away. In this regard, the ionosphere may be likened to an electrical sieve, or more correctly a series of sieves, extending around the earth at the height of the ionospheric E and F regions. If the size of the mesh of the sieve which represents the E region is specified at 4 inches, then the effective mesh size of the F region must be less, say 1 inch. High radio frequencies such as those used for television may be likened to marbles which, as shown on the chart, shoot through the ionospheric mesh into outer space,

never to return. As the radio frequency is reduced to those primarily used for short-wave communications, we find that like tennis balls, they penetrate the larger mesh of the E layer only to bound back from the F layer, thus resulting in the longer paths of communications shown on the chart. As the frequency is reduced still further, say to those of the conventional radio broadcast band, the waves may be likened to basketballs which rebound off the E region and even at night provide only relatively short communication paths. There is one more category, that of very low radio frequencies of the type which the Navy uses to maintain worldwide contact with its ships, which may be likened to long sticks which when alined with the magnetic field lines of the earth can penetrate the ionospheric mesh along the magnetic lines of force.

We know very little about the ionospheres of other planets. On theoretical grounds, one might expect ionospheres on the major planets. The detection of radio bursts from Jupiter and the optical indications of an aurora on Venus indicate that these planets, at least, may possess ionospheres similar in some regards to that of the Earth.

ADDITIONAL KNOWLEDGE ALREADY OBTAINED FROM ROCKETS AND SATELLITES

During the International Geophysical Year rocket flights in the Arctic disclosed the important fact that disturbed low-altitudes D region ionization is due to X-rays from the sun, in contrast to the ultraviolet radiation responsible for the normal higher-altitude ionospheric charging. It is hoped that more knowledge of this phenomenon may lead to the ability to forecast these important disturbances to communications in Arctic regions. It was also learned that the ionospheric regions do not have deep "valleys" between them, but rather than the ionosphere is a connected region with only minor variations in the density of charged particles, as shown on the second chart. At altitudes above the F region maximum, the Russian rocket and satellite data disclose a rather surprisingly slow decrease in density of charged particles with altitude. The density of electrons exceeds 10,000 per cubic centimeter from 100 to 1,000 miles. Thus, the bulk of the ionosphere lies above the F2 region maximum, at 180 miles altitude. Consequently, the ionosphere may have a correspondingly greater influence on communications between spacecraft and the earth than had been anticipated. In this connection, it is interesting to note that earlier estimates of the appreciable electron density about 10,000 miles above the earth's surface were not taken seriously until it became obvious that they are consistent with the Russian satellite and rocket data.

Senator STENNIS. Cover that point again, if you don't mind. What was it that had not been taken seriously until it was found to coincide?

Dr. CLARK. In this country, to explain radio reception of lightning flashes, which occurred in the Southern Hemisphere and were propagated to the Northern Hemisphere along the magnetic lines of force, theoretical physicists deduced that one would have to have electron densities about 10,000 miles above the earth's surface of the order of 1,000 electrons per cubic centimeter. This was so much greater than previous astronomical estimates of the densities in these regions that it did not seem reasonable that this could be the case.

But then when the Russian satellite data also showed very much higher levels around a thousand miles above the earth's surface, it all tended to form a coherent picture. Now with this as a background, we can list some of the most important research objectives which we have in this ionospheres program.

IONOSPHERES RESEARCH OBJECTIVES

With regard to the earth's ionosphere, we are interested in determining its sources, such as solar ultraviolet and X-radiation. By nature, we mean: What are its constituents? In the E region nitric oxide is the predominant charged particle, and in the same way atomic oxygen is predominant in the F region. What are the other constituents of the ionosphere and how do they vary with time and location? We are interested in the ionospheric distribution in space and in its variations with time. Relations between currents flowing at ionospheric levels and the earth's magnetic field are of importance, as are interactions between the ionosphere and radiation, particles, auroras, and the Great Radiation Belt. Ionospheric effects on communications and other space flight operations will be understood better because of the results of such research.

We are also interested in other ionized regions of the solar system. Does the moon have an ionosphere? What are the natures of other planetary ionospheres and in what important characteristics are they similar to or different from that of the earth? How do the ionospheres of the planets blend at their outermost regions into the corona of the sun?

LONG-RANGE IONOSPHERES PROGRAM

The fourth chart outlines the long-range ionospheres research program. Observations of the earth's ionosphere from below, from within, and from above will be used to determine the structure and radio propagation characteristics of the ionospheric regions. Effects of the ionosphere on space flight operations and communications will be evaluated. Using the knowledge thus gained, other planetary ionospheres will be investigated, first from above, and later, as space probes come closer to other planets, from within. Such flights will provide an excellent opportunity to evaluate the effects of ionized regions in interplanetary space on space communications.

The advisability of establishing a propagation observatory on the moon is also under consideration. Such an observatory would be useful to monitor the cosmic noise which forms the background for interplanetary communications, and to investigate one-way propagation through the earth's ionosphere on a continuing basis. A lunar relay station may also be necessary in the event that very low frequencies, which will not propagate readily through the ionosphere, are used for interplanetary communication.

SHORT-RANGE IONOSPHERES PROGRAM

This chart lists the important components of the short-range ionospheres research program. The structure of the ionized regions above 200 miles will be investigated by means of propagation through this medium, by means of direct measurements in the vicinity of satel-

lites and space probes, and by radio sounding from below and from above the ionosphere. Particular attention will be paid to the variations of the density and composition of these regions with time, with season, with latitude, and with activity on the sun. Very low frequency propagation through the ionosphere will be investigated, with a view toward the use of possible "windows" through the ionosphere at these frequencies for future interplanetary communications. Cosmic radio frequency noise will be studied in the outer ionosphere, at frequencies which do not penetrate through the F region to the earth's surface. The results of such measurements will be useful in research on processes in outer space which cause these radiations, as well as in basic communication studies for which this cosmic noise may be the limiting factor in determining appropriate frequencies for interplanetary communications.

Interactions between the charged particles in the ionosphere and spacecraft will be measured, both to gain additional important data regarding the ionosphere in the region around the spacecraft, and to evaluate effects produced by such interactions on electrical measurements made from the surface of the spacecraft. Another important aspect of such measurements has to do with the increase in effective cross sections of the charged vehicle to charged particles, since like charges repel and unlike charges attract. Under certain circumstances, such electrical drag effects could cause appreciable trajectory errors.

THE IONOSPHERIC TOPSIDE SOUNDER

The equipment which is used in making these various measurements of ionospheric characteristics consists mostly of conventional miniaturized and transistorized radio receivers and transmitters. Chart 6 illustrates a particularly interesting example of such techniques in diagrammatic form. For a number of years ground-based ionospheric radio sounding stations have determined the heights of the ionospheric E and F regions by means of short radio pulses which bounce from the ionosphere, as shown on the lower left corner of the chart, and are received at the same ground station later in time, by an amount which is dependent upon the height of the ionosphere. The topside sounder is an adaptation of this method for use from earth satellites. A trigger pulse from the ground station at a radio frequency sufficiently high to penetrate the ionosphere causes a lower frequency pulse to be transmitted from the satellite. This pulse is in turn reflected from the various ionospheric regions, and subsequently telemetered back to the ground station. In this manner a simultaneous indication can be obtained of the ionospheric characteristics from below and from above.

This experiment is also of interest from another aspect. The Canadians are particularly interested in arctic ionospheric characteristics, because of their unusual radio communication problem associated with the presence of the disturbed auroral zone over much of the country. Consequently, they have offered to contribute some 20 man-years of effort to the design, development, and construction of rocket, satellite, and ground-based equipment for this experiment. The United States would be expected to provide the sounding rocket and satellite booster systems. This is both a most effective type of international cooperation, and a highly valuable means for broadening the base of the total space research effort.

TWO-YEAR SCHEDULE IN IONOSPHERIC RESEARCH

As shown on this chart, during the next 2 years seven sounding rockets, five earth satellites, and one space probe are programed for the ionospheric research which we have been discussing. This represents a good start, but only a start, in the investigation of these important problems.

Senator YOUNG. May I ask one question here, Mr. Chairman?

Senator STENNIS. All right, Senator Young.

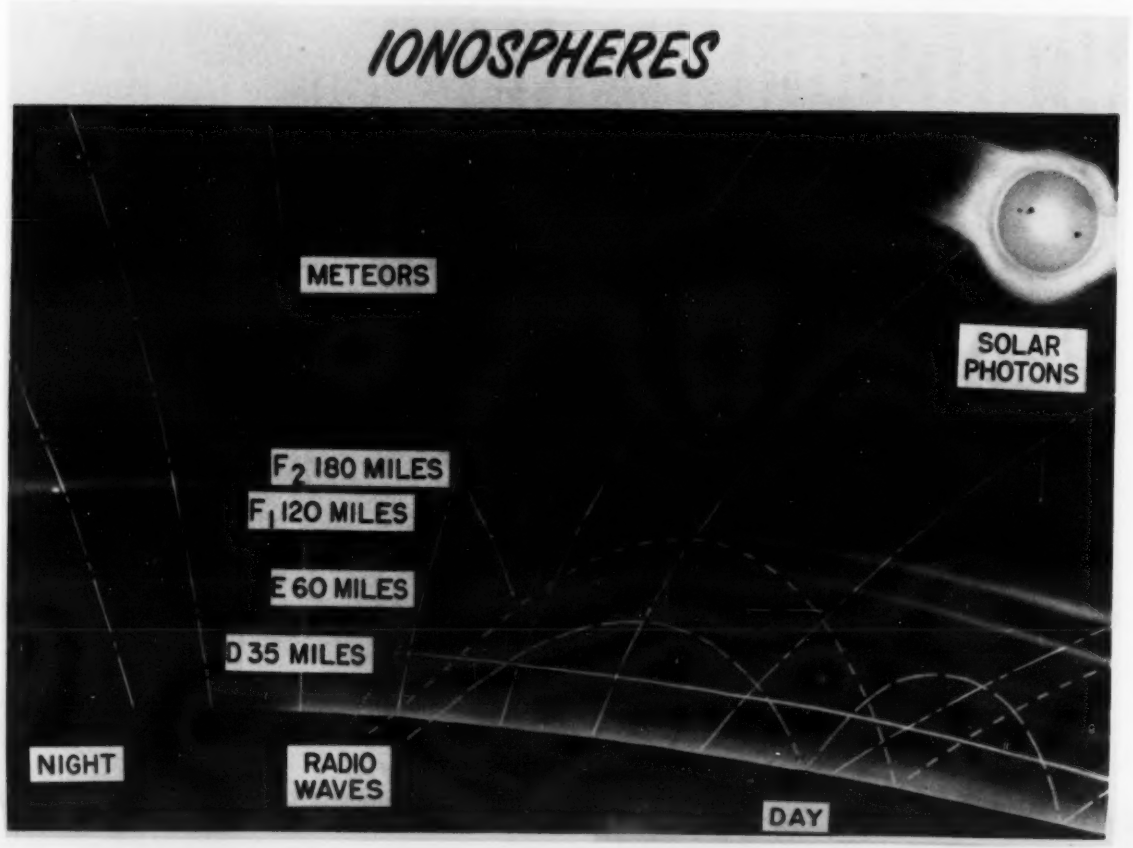
Senator YOUNG. Doctor, assuming that I want to tell someone in simple language what the ionosphere is, will you give me the language? Will you tell us how that would be explained in a few minutes' time?

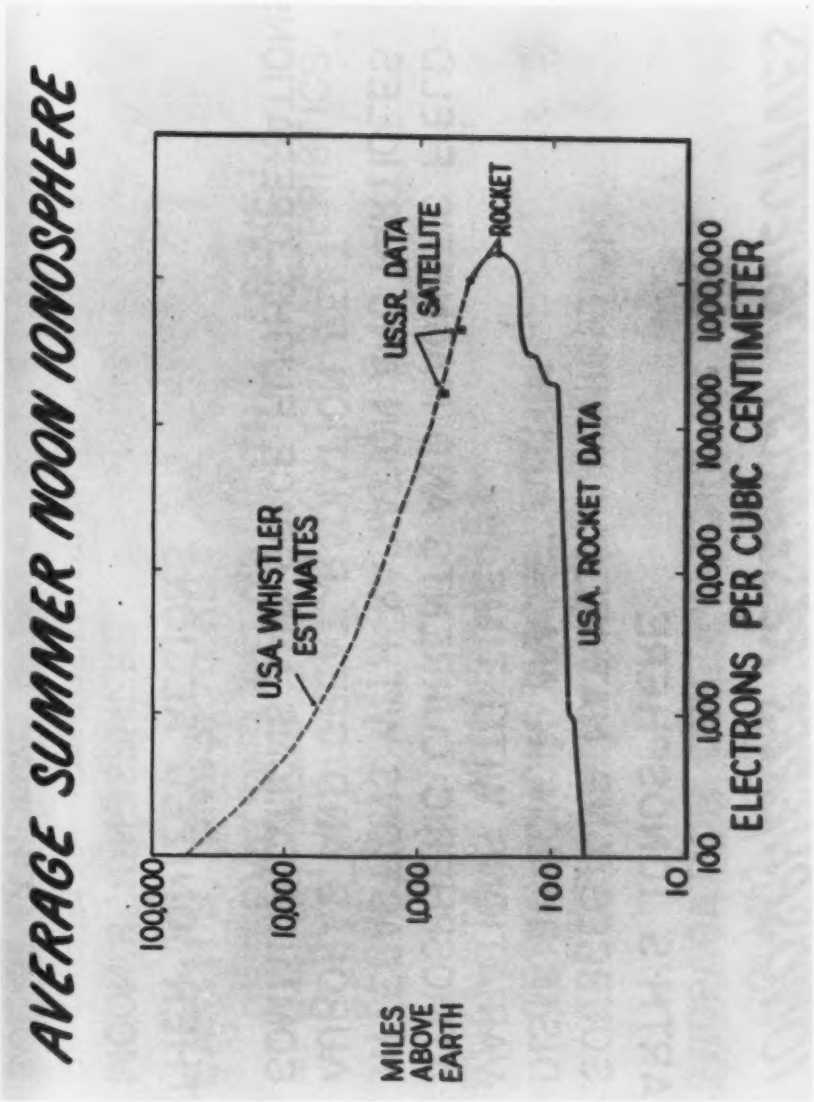
Dr. CLARK. Yes, sir. The ionosphere is a part of the atmosphere, and the thing which distinguishes it from the rest of the atmosphere is that the particles which make up the gas of the ionosphere are electrically charged. Because the gas molecules are exposed to the sun's radiation, this intense radiation actually separates an electron from the rest of the molecule, and so we have the free electron which is responsible for most of the ionospheric effects, and we have the remaining part of the molecule which is now called an ion, and together these provide the charged particles that make up the ionosphere.

Senator YOUNG. And about how long has that term been in existence?

Dr. CLARK. About 40 years. Our knowledge of the ionosphere first came into being in the second decade of this century. Most of the work was done by Heaviside in England in which he postulated that the long-range radio communications which Marconi had observed could only be explained by the ionosphere, a conducting and reflecting layer in the earth's upper atmosphere. This turned out to be so.

THE IONOSPHERES RESEARCH PROGRAM


IONOSPHERES
METEORS
SOLAR PHOTONS
F2 180 MILES
F1 120 MILES
E 60 MILES
D 35 MILES
NIGHT
RADIO WAVES
DAY


AVERAGE SUMMER NOON IONOSPHERE
MILES ABOVE EARTH
100,000
10,000
1,000
100
10
USA WHISTLER ESTIMATES
USSR DATA SATELLITE
ROCKET
USA ROCKET DATA
100
1,000
10,000
100,000
1,000,000
ELECTRONS PER CUBIC CENTIMETER

IONOSPHERES RESEARCH OBJECTIVES

EARTH'S IONOSPHERE

- SOURCES AND NATURE
- DISTRIBUTION IN SPACE
- VARIATIONS WITH TIME
- ATMOSPHERIC CURRENTS AND MAGNETIC FIELD
- INTERACTIONS WITH RADIATION AND PARTICLES
- AURORAS AND GREAT RADIATION BELT
- COMMUNICATIONS AND SPACE FLIGHT OPERATIONS

OTHER IONIZED REGIONS

- MOON'S IONOSPHERE
- PLANETARY IONOSPHERES
- SOLAR CORONA

PLANETARY IONOSPHERES
SOLAR CORONA

LONG RANGE IONOSPHERES PROGRAM

EARTH'S IONOSPHERE
- OBSERVATIONS BELOW, WITHIN, ABOVE
- STRUCTURE, PROPAGATION CHARACTERISTICS
- EFFECTS ON SPACE FLIGHT

PLANETARY IONOSPHERES
- OBSERVATIONS ABOVE, WITHIN
- EFFECTS ON SPACE COMMUNICATION

PROPAGATION OBSERVATORY ON MOON
- COSMIC NOISE
- PROPAGATION THROUGH EARTH'S IONOSPHERE

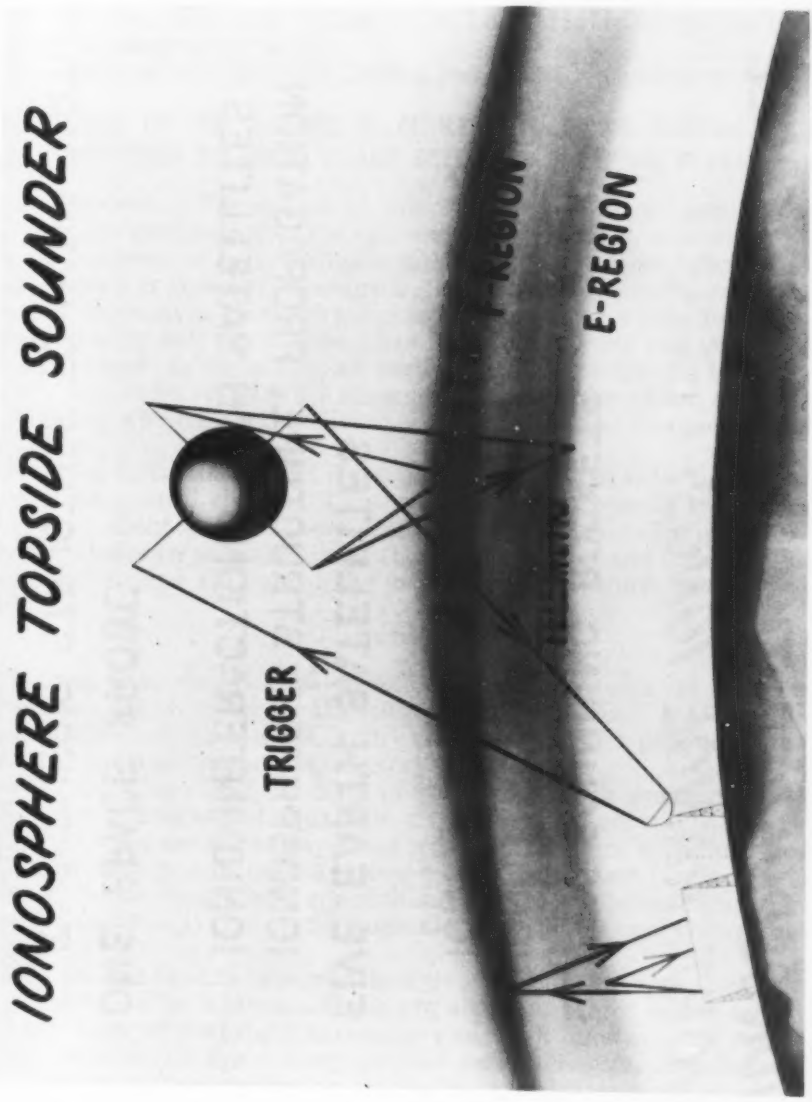
SHORT RANGE IONOSPHERES PROGRAM

IONOSPHERIC STRUCTURE ABOVE 200 MILES

VERY LOW FREQUENCY IONOSPHERIC PROPAGATION

COSMIC NOISE IN THE OUTER IONOSPHERE

INTERACTIONS BETWEEN CHARGED PARTICLES AND SPACECRAFT


IONOSPHERE TOPSIDE SOUNDER
TRIGGER
E-REGION

IONOSPHERES TWO YEAR SCHEDULE

SEVEN SOUNDING ROCKETS

IONOSPHERIC STRUCTURE, VLF PROPAGATION
IONIC INTERACTIONS WITH ROCKETS

FIVE EARTH SATELLITES

IONOSPHERIC STRUCTURE, PROPAGATION
IONIC INTERACTIONS WITH SATELLITES

ONE SPACE PROBE

IONOSPHERIC STRUCTURE TO MANY EARTH'S RADII

Senator STENNIS. Thank you very much, Doctor. We will come to a natural break following this next witness, will we not, Doctor?

Dr. NEWELL. That's correct.

Senator STENNIS. We will have a break then and everyone can ask questions. Doctor, who do you have next?

Dr. NEWELL. The next witness is Dr. Leslie H. Meredith who will talk about energetic particles.

Senator STENNIS. All right, Doctor, just proceed in your own way.

TESTIMONY OF DR. LESLIE H. MEREDITH, HEAD, FIELDS AND PARTICLES BRANCH, SPACE SCIENCES DIVISION, NASA

Dr. MEREDITH. The subject of this short talk is the energetic particles which are present in the space around the earth, and what the NASA program is to investigate these particles. More specifically this program is aimed at investigating cosmic rays, the particles which produce the auroras, northern lights, the particles which form the great radiation belt which Van Allen found during the past year, and then for these various classes of particles their interactions with the earth's atmosphere and with other atmospheres, the effects of these particles on materials and on living organisms, and the origins of these particles.

For ease in talking about these particles we have split them into these three general classes. This has been done primarily as an ease in talking about them. There are, however, undoubtedly interrelationships between the particles of these three classes, and indeed these interrelationships are one of the many problems which we have to look into.

AURORAS

Of these three classes of particles, the auroral particles are the ones which man has observed for the longest period of time. It is the impact of these particles on the earth's atmosphere which produce auroras which are sometimes called the northern lights.

These sometimes take the form of a drapery which goes across the sky and sometimes as just a quiet arc. Other times there will be a large bundle of what are called rays, and when the rays are straight overhead they may appear like the corona shown on the chart [indicating]. The aurora can change from one of these forms to a different form very rapidly, and this is one of the questions as to just exactly why this happens.

They can also be very faint and then very suddenly increase markedly in intensity. The faintest auroras are about as bright as the milky way and some of the brightest ones give as much light as a full moon. About the start of this century ground based measurements showed that there were two regions on the earth in which auroras could be seen almost every clear night. These two zones are shown in green on this figure.

As you go either north or south from these two zones the frequency of auroras drop off, and as you know here in Washington you see auroras about once a year or something in that general order.

It was not until just this past year, however, that rockets were actually fired into these visible auroras. These were fired as part of

the IGY from the Fort Churchill area in Canada. These rockets showed that auroras are produced by electrons incident on the earth's upper atmosphere. This is just a start of the program because we found that there are also protons incident on the stratosphere and many other complicated features.

About at the start of this century it was found that there were also other particles incident on the atmosphere. These particles have very high energy and indeed produce effects all the way down to the earth's surface.

COSMIC RAYS

Since their discovery these particles called cosmic rays have been measured from deep mine shafts to far out into space and from one pole of the earth to the other. As a result of all these measurements, it has been found that these cosmic rays are coming to the earth uniformly from all directions.

At the Equator the earth's magnetic field, which is shown by the light lines on the chart, bends these particles so that only the high energy ones shown in red can reach down to the earth, and the lower energy ones are thrown out.

As you go either north or south, however, the particles do not have to cross so much of the magnetic field, and at the poles all of the particles can get in, both the high energy ones and the low energy ones, as they don't have to cross the field at all. By measuring this change in the intensity of these particles with latitude, and by many other means, we have been able to find out what the energy spectrum of these particles is, and this chart shows what we have found.

Now this chart doesn't mean to imply that this is a firm curve. There are many questions as to exactly what the spectra is in this low-energy region, and this is one of the things that our program is aimed at. Also, the spectrum is known to vary.

From this curve, however, you can see that the cosmic rays have a very high energy. Here on the curve you have 1 million billion electron volts. As a point of reference, the highest energy a particle accelerator which is on this earth can accelerate particles to about 10 to 15 billion electron volts which is about here on this particular curve.

While the individual particle energies are very high, the intensity of these particles is very low, and the total energy brought to the earth by these particles is of the order of energy brought by starlight. The particles themselves are the nuclei of atoms. About 90 percent of the cosmic rays are protons or the nuclei of hydrogen atoms. Most of the remaining 10 percent are the nuclei of helium atoms. The 1 or 2 percent that are left are the nuclei of heavier atoms such as carbon, oxygen, calcium, and all the way out to iron.

RADIATION BELT

The most recently discovered of these energetic particles are those which form the radiation belt. This chart gives a scematic picture of what the belt is. We don't really know yet in any detail exactly what the shape of the belt is. Nor do we know what kind of particles there are in these belts. The belt itself is a doughnut-shaped ring which goes around the earth and there are actually two of them, one ring around here and one ring around here.

What we do know is that the intensity of the particles in these regions is something about 10,000 times as high as what the cosmic ray particle intensity is, and they are undoubtedly lower energy particles than the cosmic ray particles. It is very likely that the particles in this belt have a very direct relationship to the particles which produce the northern and southern lights which would occur here on the earth.

There are many questions which remain to be answered as to just what this radiation belt is.

FUTURE ENERGETIC PARTICLES PROGRAM

The NASA program to investigate all these many problems during the next 18 months is shown in this chart. We plan on firing one satellite plus two space probes to investigate the cosmic ray intensity in interplanetary space; one satellite to measure cosmic ray fluctuations, that is variations with time; one space probe plus two rockets to measure the cosmic ray energy and charge spectrum; two satellites plus four rockets to measure the radiation belt composition and extent.

That is what kind of particles there are in the radiation belt and to map it out better; and we are planning on firing six small rockets to measure auroral particles.

THE ENERGETIC PARTICLES RESEARCH PROGRAM

OBJECTIVES OF ENERGETIC PARTICLES STUDIES

COSMIC RAYS

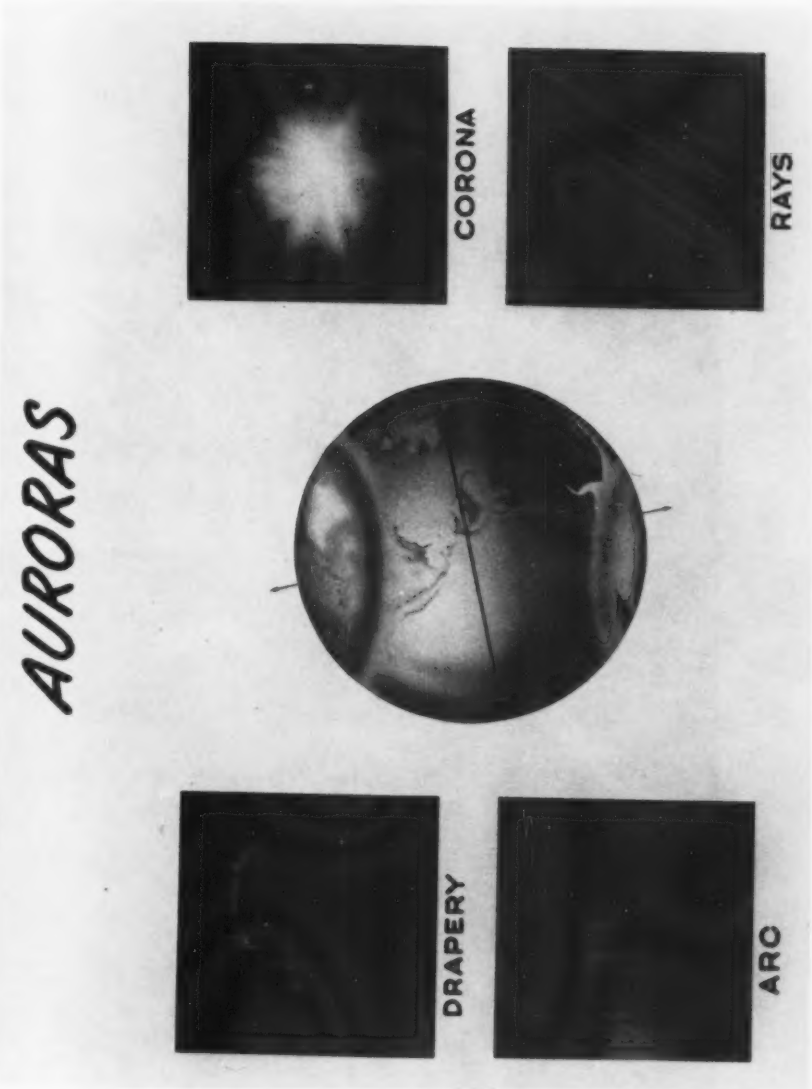
AURORAL PARTICLES

GREAT RADIATION BELT

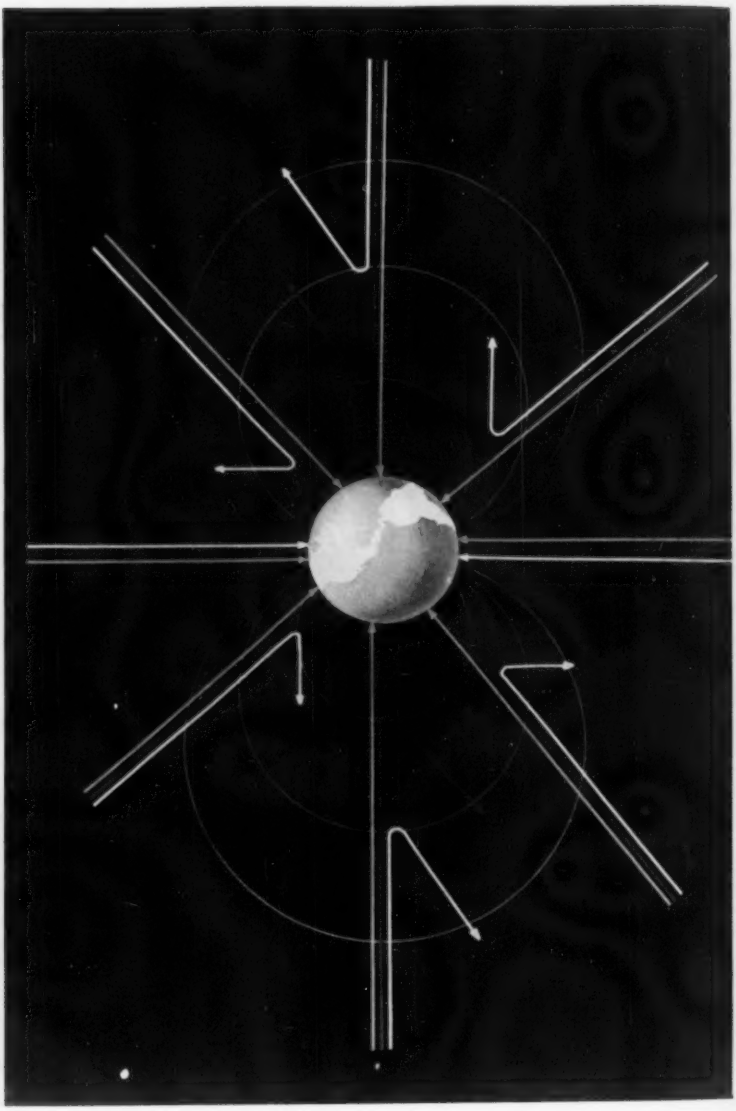
INTERACTIONS OF PARTICLES WITH ATMOSPHERE

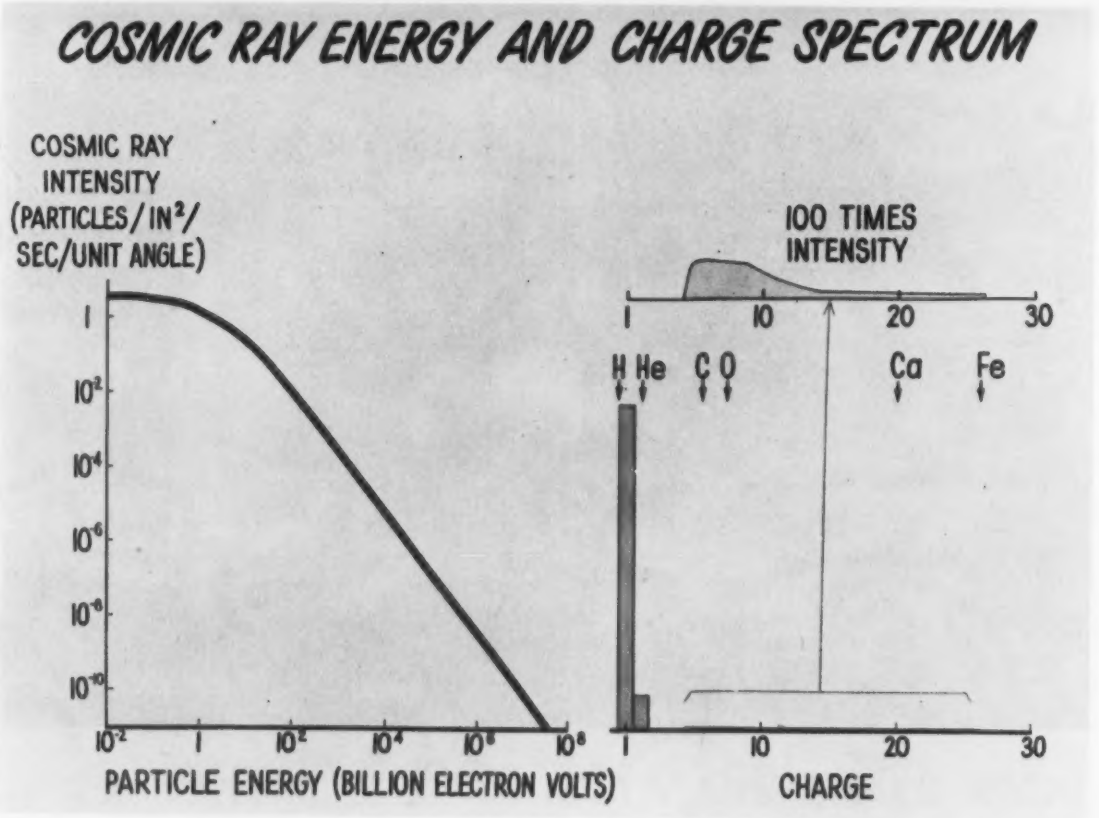
EFFECTS ON MATERIALS AND LIVING ORGANISMS

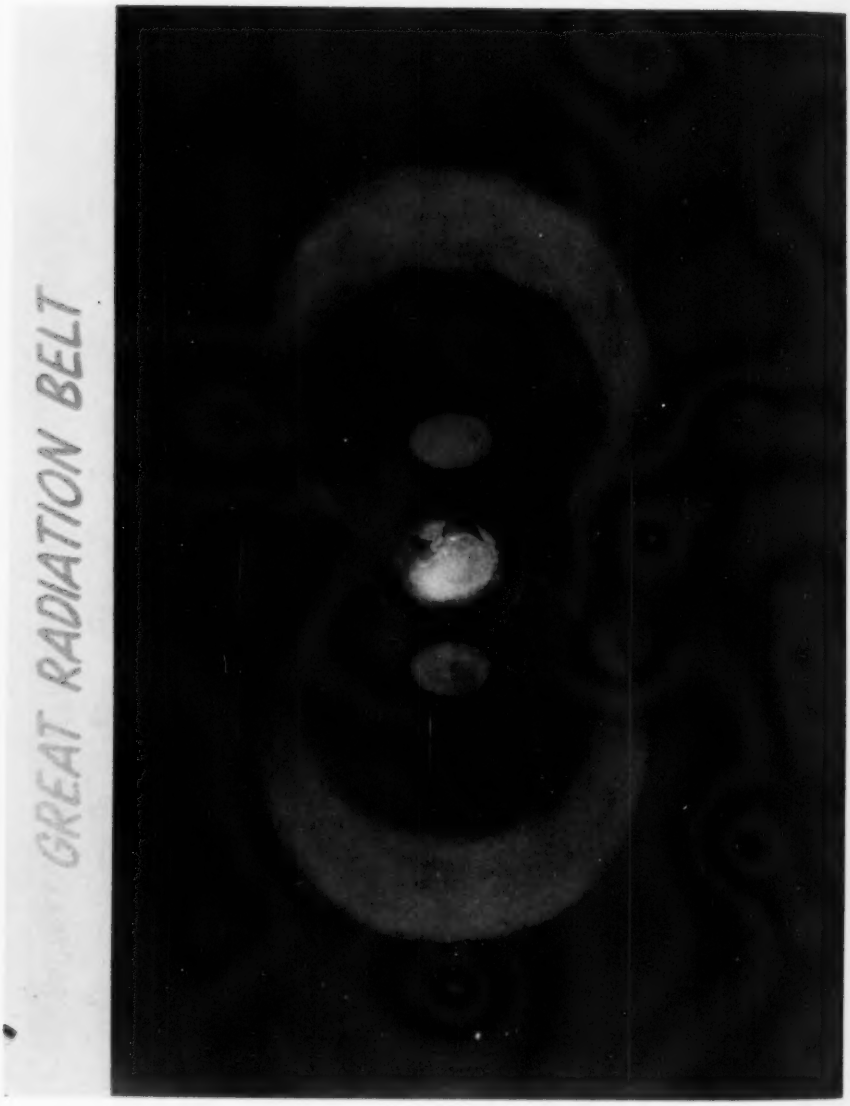
ORIGINS


AURORAS
CORONA
RAYS
DRAPERY
ARC

EFFECT OF LATITUDE & ALTITUDE ON COSMIC RAY INTENSITY




COSMIC RAY ENERGY AND CHARGE SPECTRUM
COSMIC RAY INTENSITY (PARTICLES/IN²/SEC/UNIT ANGLE)
1
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻²
1
10²
10⁴
10⁶
10⁸
PARTICLE ENERGY (BILLION ELECTRON VOLTS)
100 TIMES INTENSITY
1
10
20
30
H He C O
Ca
Fe
1
10
20
30
CHARGE


GREAT RADIATION BELT

18 MONTHS ENERGETIC PARTICLES PROGRAM

PURPOSE	NUMBER OF LAUNCHINGS
COSMIC RAY INTENSITY IN INTERPLANETARY SPACE	THREE SPACE PROBES
COSMIC RAY FLUCTUATIONS	ONE SATELLITE
COSMIC RAY ENERGY AND CHARGE SPECTRUM	ONE PROBE PLUS TWO ROCKETS
RADIATION BELT COMPOSITION AND EXTENT	TWO SATELLITES PLUS TWO PROBES
AURORAL PARTICLES	TWELVE SMALL ROCKETS

Senator STENNIS. All right, Dr. Meredith. We thank you very much—and you suggest this as a breaking place now for some questions.

TEMPERATURE OF THE MOON

There is one request that I am going to make, that you bring back that first chart you had here that had such a striking line on it with reference to the temperature as you go up—you said something about the temperature on the dark side of the moon being 243° minus F.

Dr. NEWELL. Yes.

Senator STENNIS. How did you measure that?

Dr. NEWELL. Well, one did not measure it, but calculated it theoretically. When the moon surface is illuminated by the sun, of course, the heating effect is due to the energy brought in by the sun's rays. Now, we can see the sun's surface when the moon is full, and we can measure the temperature by means of radiometers, the sort of devices that are used to measure the temperatures inside of furnaces in steel mills.

Senator STENNIS. What I was really coming to, Doctor, is when we talk about landing on the moon, you are not going to land on that side, I judge.

Dr. NEWELL. No, but it might be better to land on that side than the other side.

Senator STENNIS. Is that so? Why do you say that?

Dr. NEWELL. You can protect yourself against the cold by proper dress.

Senator STENNIS. I see.

Dr. NEWELL. I would assume in the first landing one would plan to land in the zone between the very hot and the very cold regions.

Senator STENNIS. What is your calculation about the situation there—that the place where you would land would be normal, is that it?

Dr. NEWELL. Yes. As twilight approaches on the moon, the energy is radiated away and gradually the surface cools off.

Senator STENNIS. I just wanted all to see that temperature line, the red line. Now, do I understand as you go to, say, 200 miles in height, that relatively the atmosphere there is over 2,000° F. plus?

Dr. NEWELL. Yes, that is correct.

Senator STENNIS. All right.

Senator Smith, do you have any questions?

Senator SMITH. I have no questions.

Senator STENNIS. Senator Young?

Senator YOUNG. I have no questions.

Senator STENNIS. Senator Dodd?

Senator DODD. I was wondering, are these colors used to make the chart more understandable?

Dr. NEWELL. Yes.

Senator DODD. You do not know whether what they represent are red or not?

Dr. NEWELL. There is no significance to the color. Red is used simply because one thinks of the radiation belt as hot because of the extreme intensity.

Senator STENNIS. Do you have something further?

Senator DODD. No.
Senator STENNIS. Senator Cannon.
Senator CANNON. Thank you, Mr. Chairman.

FURTHER REFERENCE TO WORK OF CHRISTOFILOS

Doctor, yesterday Senator Wiley asked a question about Nicholas Christofilos and his ideas about high-altitude explosions. Is there someone here in your group who could perhaps explain to us what effect, if any, these high altitudes have on these radiation belts so far as the communications problem is concerned? You are bounding off the waves on communications, so far as that is concerned.

Dr. NEWELL. I can take that, or Dr. Meredith can.

Senator CANNON. Yes.

Dr. NEWELL. You will notice the shape of these belts fit very much the shape of the earth's magnetic field. You can think of the earth as a magnet; just think of a little bar magnet going through here, with the North Pole and the South Pole, and the lines of magnetic strength go from the North Pole to the South Pole so that you can imagine in space these lines of differing strengths. They form a shape very much like the shape shown here.

Now, if you inject into a magnetic field the charged particle, and it doesn't have enough energy, it will be trapped there. The magnetic field tends to deflect particles so they cannot go in a straight line. So if you think of a charged particle as being injected here, and attempting to move out of the earth's magnetic field, it really is going to be deflected this way as it attempts to move, and it will just wind back on itself and sort of twist around the magnetic field line.

If you have too low an energy particle it can't get away. It just twists around in the magnetic field. Now, if then, for example, you were to send up into this region of space a device that creates lots of electrons, you could populate that region in space with those electrons because they would be trapped there. A nuclear explosion will produce a lot of electrons. So that if you can generate a high-altitude explosion, the electrons will get captured.

Now, Christofilos' point is that high-altitude explosions will fill up rings like this.

Senator STENNIS. Will fill up what?

Dr. NEWELL. Fill up rings around the earth like this, trapped in the earth's magnetic field. Now, electrons are charged particles and have the property of being able to reflect radio waves, but they also have the property of being able to absorb them. If you get too many of them they will absorb radio waves.

Thus, Christofilos' point is if these rings get too crowded with electrons, radio waves going through these regions will be absorbed and you will have an interference with radio propagation. And this, apparently, is what did occur at the time of some of the high-altitude tests.

Senator CANNON. Now, to go a step further and explain to us just what the actual results were in everyday language—was radio communications cut out, was it so garbled that it could not be used, or what?

Dr. NEWELL. My understanding from reading over some of the results was that at the time of the explosions there was a blackout of radio communications so that signals were not getting through by the mutual shortwave nets, and the fact, I understand, that some of the airlines held up the takeoffs on some of their flights because the communications were interrupted. The conclusion seems to be that the interruption must have been due to the electrons injected into these regions.

Senator CANNON. Do you know how long that interruption occurred?

Dr. NEWELL. A matter of hours.

Senator CANNON. So that this field eventually dissipates, does it not, or the condition that exists?

Dr. NEWELL. Yes. The closer these electrons are to the earth, the faster the effect dissipates. The electrons collide with the air molecules, they are absorbed by the air molecules and disappear. The higher the region the longer it stays in existence because there is no interference with air molecules to destroy it. On the other hand, the higher the region the less interference with communications.

Senator STENNIS. Senator, would you yield for what is a relevant question on that point? Ask him what is going to be done in following that up.

OVERCOMING PROBLEM OF COMMUNICATIONS INTERFERENCE

Senator CANNON. That is what I was going to ask. What are we doing, if anything, to try to overcome that supposed hazard?

Dr. NEWELL. At the present time I think we are in position to go after a search for knowledge first, and a large part of the program Dr. Meredith described is devoted to identifying these regions where particles can be trapped, identifying the particles that are naturally there. Then we can know when other particles are inserted and can compare them. I would say at the moment a major effort is directed toward completely understanding the picture.

PROBLEMS CAUSED BY RADIATION BELT

Senator CANNON. Is this radiation belt on the chart one of the problems you are going to have in putting a man into space? Perhaps you should go to your cosmic chart there where you are bounding the cosmic rays out. Is that going to be one of the big problems, cosmic radiation, so that if a man was placed into space he should be placed, according to this chart, around the Equator rather than around either one of the poles?

Dr. NEWELL. This radiation belt raises a number of problems. Although these particles are of lower energy than cosmic rays, their intensities, as Dr. Meredith said, are 10,000 or more times as great. When they impact on the surface of the vehicle they generate X-rays, and these X-rays are the hazard in this case. This means that if you are going to send vehicles up through this radiation belt, you are going to have to protect the passenger by proper shielding so that he doesn't get irradiated with those X-rays.

On the other hand, if you are thinking of a probe that comes way out here, you might be able to laugh up in this region, you see, and

avoid the region. If you are thinking of instrumentation that is interfered with by charged particles like this, for example, in orbiting astronomical observatories, you are going to have to plan so that it either stays below in this region—as you said, in the equatorial region, perhaps, or out here—and orbits outside of the belt.

There is another effect this radiation belt has, one that Dr. Clark mentioned in discussing the ionosphere, and that is a charged region like this tends to deposit a charge on the vehicle going through it, and we have indications already that the Vanguard satellite that was launched a year and a few days ago has acquired a potential of some thousands of volts. This increases the drag, the resistance, on the satellite. This is something engineers are going to have to worry about.

Senator CANNON. Is this belt out far enough so that you can safely put a man in orbit around the earth, say, up to 200 miles?

Dr. NEWELL. Yes; you probably could.

Senator CANNON. Particularly the equatorial area?

Dr. NEWELL. Yes.

Senator CANNON. That is all, Mr. Chairman.

Senator STENNIS. Senator Smith, do you have something further?

Senator SMITH. No.

Senator STENNIS. Senator Young?

Senator YOUNG. Nothing further.

Senator STENNIS. Senator Dodd?

Senator DODD. Nothing further.

Senator STENNIS. I have one other question here while you are on the subject of communications that were interrupted.

Dr. NEWELL. Yes.

Senator STENNIS. Do you think that was caused by this Argus experiment, or by your Johnston Island test shots?

Dr. NEWELL. It is my understanding it was the Johnston Island test shots. I could check that and put it in the record for you.

Senator STENNIS. I wish you would.

(The following information was subsequently provided by NASA:)

High-altitude nuclear explosions set off over Johnston Island in early August knocked out radio communications for 700 miles and created an artificial aurora which was reported by New Zealand scientists in Samoa (from Time magazine, March 20, 1959, science section).

Senator STENNIS. How long did these interruptions last, did you say, when the communications with the airlines were interrupted?

Dr. NEWELL. I understood for several hours. It raises a lot of interesting questions.

Senator STENNIS. Yes.

EXTENT OF RUSSIAN SATELLITE DATA COOPERATION

Dr. Clark had mentioned the calculations that had been made but not paid much attention to until they were confirmed by a Russian satellite. Do they make available to you the findings of their satellites?

Dr. CLARK. Yes; they did.

Senator STENNIS. To what extent do they make it availbale?

Dr. CLARK. The Russians make available that portion of their results which they want us to have.

Senator STENNIS. Yes.

Dr. CLARK. The results are selected, and we consistently have problems in obtaining some of the raw data on which their conclusions are based. They will give us information as to the conclusions from analysis of the data, but not make the raw data available.

One additional comment on not taking the other computations seriously, I don't think I made that adequately clear in the presentation. It was not a case of failing to take the "whistler" lightning results into consideration. It was that there were two conflicting sets of conclusions from different approaches, and we weren't sure which was correct. The Russian data then provided the connecting link.

Senator STENNIS. Back to this interference for just a minute, gentlemen. This involves, as you know, one of our antimissile-missile programs. In addition to the work you are doing on this problem, what is the rest of the program on that?

Dr. NEWELL. In the Department of Defense?

Senator STENNIS. Yes. Do you know?

Dr. NEWELL. I don't know.

Senator STENNIS. You do not know.

Mr. Lehrer, do you have some questions you would like to ask?

Mr. LEHRER. I would like to follow up the question on the interchange with the Russians. Have we tried to get from the U.S.S.R. the raw data through official channels or through the IGY channels?

Dr. CLARK. Since Dr. Newell was present at the Moscow meeting last summer, I would like to ask him to answer the question.

Dr. NEWELL. The answer to your question is "Yes, we have." We have tried both informally in discussions with scientists themselves, and formally through the National Academy of Sciences. In the case of the formal requests, a specific example is that of our attempting to get data on the orbits of the Russian satellites so that we might be able to use these data for our own theoretical researches, and consistently we have been turned down.

Mr. LEHRER. Is this a breach of the IGY understanding?

Dr. NEWELL. Not really, because the Soviets have consistently refused to adopt in our general IGY negotiations the agreement to interchange these particular data.

Mr. LEHRER. In view of the Soviet action, what are we doing with respect to our raw data, do we make them frequently and completely available to the Soviets?

Dr. NEWELL. We make our data available to the world data centers of the IGY. These world data centers exist in the United States, in Moscow, and there is one that is spread out in various places around the world. This means our data are available to the Soviets.

Mr. LEHRER. So that we give them everything that we have, notwithstanding the fact that they do not reciprocate?

Dr. NEWELL. Yes. I would like to define technically what I mean by "raw data," so that it is clear what we do give her. We don't take the data as it comes into the recording stations and simply send that out, because in many respects it is useless. We take this mass of data and apply the necessary calibrations and reductions to usable form, and that is what we make available.

Senator STENNIS. All right, if there are no other questions—you want to go into another phase, do you, Doctor? Who is your next witness?

Dr. NEWELL. Yes, I would say that after the next two talks, at the end of the astronomy talk, that would be a convenient breaking point.

Senator STENNIS. All right. Let us proceed.

Dr. NEWELL. The next speaker is Dr. Robert Fellows, who will talk about the study of various fields in space.

Senator STENNIS. All right, Dr. Fellows. I hope the committee can stay until 12:30 at least.

TESTIMONY OF DR. ROBERT F. FELLOWS, HEAD, CHEMICAL AERONOMY PROGRAM, NASA

Dr. FELLOWS. It is very intriguing to realize that although we live in a world of physical phenomena which are governed by fields, scientists have very little realization of the true nature of a field.

A field is usually described by the effect it produces and we are all familiar with the use of magnetic fields in the generation of current, the use of a compass in the Earth's magnetic field for navigational purposes, and the effect of the Earth's gravitational field on climbing stairways. It is much, much harder, and we put more work into it than we do when coming down the stairs.

Fields are important to us for very many practical reasons. In addition, we are all interested in learning more about the fundamental nature of fields.

One very practical observation is that fields actually control the motion of all free particles, whether it be the tiniest electron, a body like an apple falling to the Earth, the Moon in its orbit around the Earth, all the planets orbiting in solar systems, and even the galaxies, all of these are controlled by laws describing behavior in fields.

THE EARTH'S MAGNETIC FIELD

The first field I would like to discuss in some detail is the Earth's magnetic field. We have the diagram here.

This globe represents the Earth. We have the North Pole of the Earth and a South Pole. I am speaking now in this particular case about the axis of rotation of the Earth. About 10° or 11° inclined from the axis of rotation we have another axis, the magnetic axis. Scientists often describe the Earth's magnetic field by imagining a bar magnet to be located in the center of the Earth. In this case the magnetic lines would travel between the north and south magnetic poles and describe closed loops, going on and on into the far distance and becoming infinitesimal in strength.

This magnetic field is not constant. It undergoes a number of types of changes. One of these changes is one occurring over periods of roughly months to years. This change, a rather slow progressive change that moves back and forth over the course of a century or so, is one that necessitates revision of all of our navigational charts about every 5 years to bring the charts up to date with the latest magnetic data.

There are also other changes of very much shorter cyclic nature that occur, and if we were to make very sensitive magnetic measurements somewhere in the middle northern latitudes, we would find the magnetic field undergoes very slight changes from day to night, an oscillation or variation which varies with our day-to-night cycle.

If we go down to the equator and make these same measurements, we find that the intensity of these variations may be as much as 10 times greater than they are in the middle latitudes. If we go to the extreme latitudes where aurora are very, very common, we find the intensities of these changes in magnetic field strength may be as much as a hundredfold higher.

We have theories which describe or account for variations of this type as being due to electric currents in the ionosphere. There are also other types of changes, and these are more irregular, perhaps more prolonged at times. We refer to these as either magnetic disturbances, or magnetic storms. If occurrence is over a very wide area including the entire earth, we call it magnetic storm.

We have reason to believe that these disturbances or storms are due to electric currents and interactions which are taking place outside of our ionosphere.

For a number of years and during the IGY especially, rockets were sent into the ionosphere and the atmosphere at a variety of locations including the equator and regions of auroras. These rockets gave scientific data which indicated the presence of electric currents in the ionosphere, but the experiments also indicated that a great many more measurements were necessary before we had sufficient data to really begin to think in detail about an explanation or a comprehensive theory covering these phenomena.

As an example of what might bring about changes in the magnetic field of the Earth, we have diagramatically illustrated the Earth again with its magnetic field. Coming in, let us imagine from the direction of the Sun, is a cloud of ionized gas.

Ionized gas is composed of particles which bear electric charges, and charges in motion generate a magnetic field. Thus, the particles with their own electric charges will have certain interactions with the Earth's magnetic field.

One result of these interactions is that the magnetic field may undergo what we call a compression. In this case an observer on the surface of the Earth will notice that the intensity of the magnetic field has increased.

Under certain other conditions of energies, types of particles, and so forth, the particles may be captured; that is, they may be trapped by the magnetic lines of force of the Earth's magnetic field. This may result in changes in intensity and in the particular case shown here, the weakening of the magnetic field of the Earth at the Earth's surface.

Under certain conditions these particles are trapped for appreciable lengths of time; they will oscillate back and forth in the Earth's netic field. This could set up pulsations, small variations of a cyclic nature, occurring at the surface of the Earth. We have indeed observed such variations, but we do not have sufficient information at this time to be certain as to their cause.

MAGNETIC FIELDS IN SPACE

I covered the Earth's magnetic field, and now I am going into that portion of electromagnetic fields about which we know really nothing. We have no factual data at this time about the interplanetary field. We have tried to illustrate on this chart showing the planetary bodies,

that we know the Earth has a field; we don't know whether Venus and Mercury have fields; we know the Sun has a magnetic field and that it varies and undergoes disturbances which can be correlated with the appearance of sun spots and bursts of solar energy. We don't know whether we have an intergalactic field; we suspicion so, but the best example here is that the estimates of the intensities of this field vary by over a million. So this chart points out that we have a great wealth of opportunity left available for us in obtaining data concerning fields surrounding our planet, the other planetary bodies in space, and the interplanetary field itself.

GRAVITATION

If we will go on from electric and magnetic fields for the moment and discuss the last field which is the subject matter of this talk, a gravitational field, we go back far into history. One of the big advances of science was when the theory of Aristotle that the Earth was the center of the universe was finally overthrown by a number of scientists including Copernicus, Newton, Galileo, and Keppler. These were scientists who made painstaking observations of the planetary bodies and their times of appearance. They tabulated their data, tried to fit laws to it or to find laws that would account for the motions of these planetary bodies, and eventually they worked out the mathematical laws which described planetary behavior.

Thus, scientists worked out the laws that accounted for the behavior of the planets. Now these laws say that the orbits for these planetary bodies will generally be ellipses. For a small manmade satellite such as one of the Vanguard satellites that ellipse should be a perfect ellipse. However, nature isn't perfect, the Earth isn't perfectly round, its surface isn't perfectly smooth, and the mass distribution of the Earth varies.

Now, these irregularities will cause irregularities in the orbit of the satellite. By very precise tracking of the satellite and the tabulation of the irregularities in the orbit of a satellite, we obtain data for making calculations concerning the earth, itself.

As a result of calculations from the Vanguard satellite 1958 beta we find that we have a new idea of the earth's shape. The old one imagines it to bulge at the equator a little more than it actually does at this time. The older figure is marked on the chart, and you can see it is flatter around the middle than it is for what we now consider to be the more valid shape.

Other very minor differences and irregularities which occur in the orbit of the satellite enabled us to make calculations which also indicated that the earth is very slightly pear shaped. I would like to emphasize "very slightly." We are discussing here a distance of 50 feet or so, when the earth's diameter is roughly 8,000 miles. Note also that the sides are pulled in slightly. Other speakers will cover this in much more detail.

My main reason for including this example was to use it as an example of pointing out how very small variations, differences from perfection, mean something very, very important scientifically. The accumulation of sufficient data furnishes fuel for mental fires to evolve theories which better account for the phenomena with which we are concerned.

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THEORIES OF EINSTEIN RELATED TO GRAVITATION

Another very famous name connected with science and involving gravitation as well, is that of Einstein. He formulated some very comprehensive theories; the general, and the special or restricted, theories of relativity. I am not going into these at all except to say that what he did in effect was to try to draw together a number of concepts that included velocity at high speeds, mass of material objects, frames of reference of one object to another, our concept of time, and gravitational effects. These theories predict certain interactions. Now that space vehicles are attainable, we have one excellent opportunity of testing a portion of Einstein's theory.

One portion of his general theory says that gravitational fields slow down physical processes. This means that if we have two identical clocks, one located in the gravitational field of the earth, and another clock located in a much weaker or gravity-free position, that the clocks will indicate different times if we let them run for a sufficiently long time.

We plan to put a special kind of clock in a satellite and have it telemeter its time down to an earth receiving station. We will then compare the satellite clock with an identical clock which is running in an earth station the entire time. After a period of time the satellite clock, by virtue of being in a lesser field of gravity than the earth clock, should run faster and gain time compared to the earth clock. So we stand an excellent chance of verifying Einstein's theory.

The other picture is put on simply to indicate that no experiment really is a simple one when you get down to the details of it. We realize we must watch out for certain other effects. If the satellite is too close to earth we may actually end up with an opposite effect, or the two opposing effects may counterbalance and we would then obtain no difference.

But there are details. The fundamental point we know we must observe in this test is that the satellite should be of the order of 4,000 or 5,000 miles out from the Earth to give us an opportunity of checking this very important part of Einstein's general theory of relativity.

The gravitational field program intended for the next 2 years will include one satellite for geodetic measurements. This would be a satellite so designed that we could track it and determine its position and its orbit with a very high degree of precision. This would enable us to make continuing calculations of the Earth's size and shape, and of intercontinental distances. Some of this, as I have indicated, has been done with the data from the Vanguard.

Also one satellite would have a clock mechanism in it and would serve as a test of the general theory of relativity.

ELECTRIC AND MAGNETIC FIELDS PROGRAM

The program for electric and magnetic fields would include two satellites which would be placed into orbits designed to give us much more information about magnetic storm bursts, when they occur, the intensities, the magnetic effects that are going on, and so forth. Of course magnetic fields are tied in very, very closely with the recently discovered radiation belt. The magnetic field around the Earth, together with other conditions, determines the pattern of the great radiation belt.

Another satellite would be launched into a different type of orbit, a polar orbit. This would serve to give us a more detailed space map of the Earth's magnetic field.

Senator STENNIS. Excuse me now one minute for clarification; when you say program, these are programs that you are definitely outlining here that are really in your budget for next year, is that correct?

Dr. FELLOWS. That is correct.

Senator STENNIS. I just wanted to be certain.

Dr. FELLOWS. Yes, sir.

Senator STENNIS. Proceed.

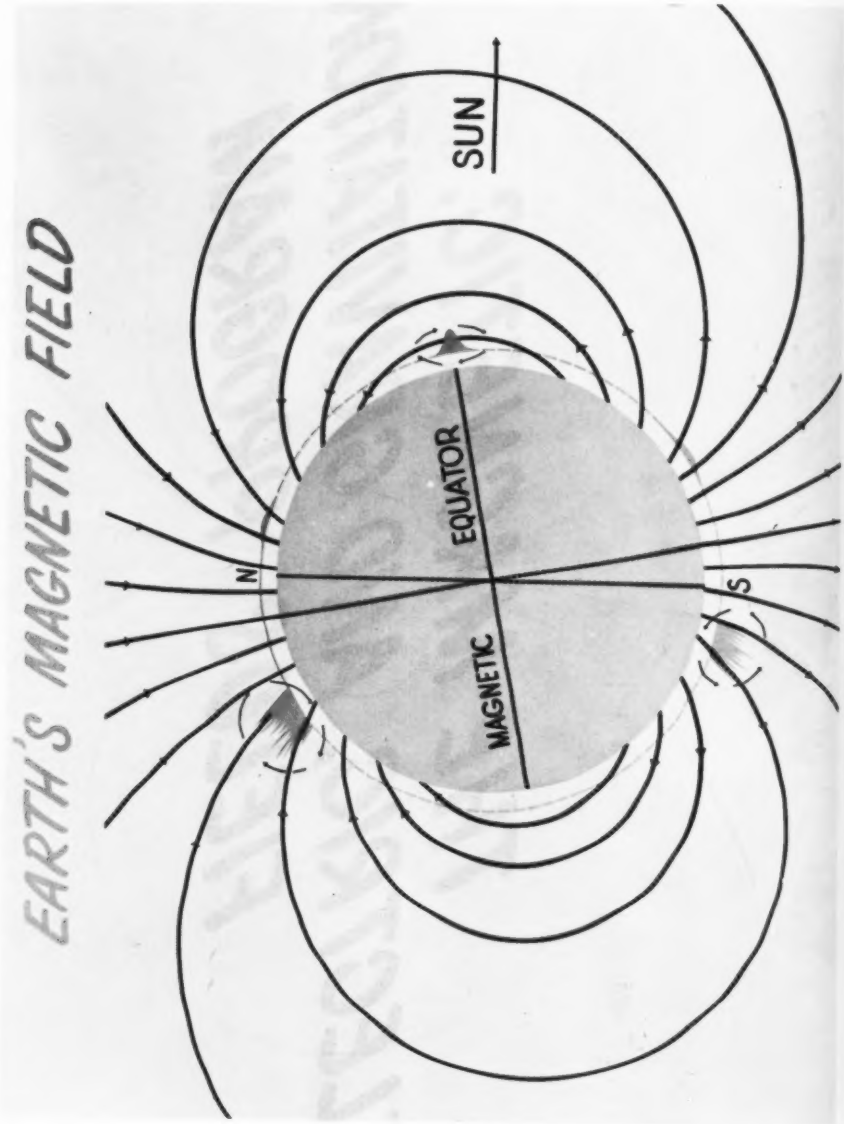
Dr. FELLOWS. Also we plan a space probe which would give us information about the Earth's far field, the Moon's field, and as much as possible about the interplanetary fields. We have very little information about these last two and what we have is really speculation and not fact.

Approximately 30 sounding rockets will be sent up into the Earth's high atmosphere and the ionosphere to give us more information about the magnetic fields and electric currents in the ionosphere. Also, we will be able to test new instrumentation to make certain that it functions properly in a space vehicle location before sending it up in a more expensive space probe or a satellite.

Also, because some of the instruments used for these measurements are light and compact, we can have a number of "hitchhike" experiments going in very large satellite or space probes. In this way we will obtain additional information about the field of Venus or some other planet, and about the interplanetary fields between here and the other planets. From these measurements we can obtain knowledge about the distortion of the Earth's magnetic field as we go farther away from the Earth.

I thank you.

THE MAGNETIC, ELECTRIC, AND GRAVITATIONAL FIELDS PROGRAM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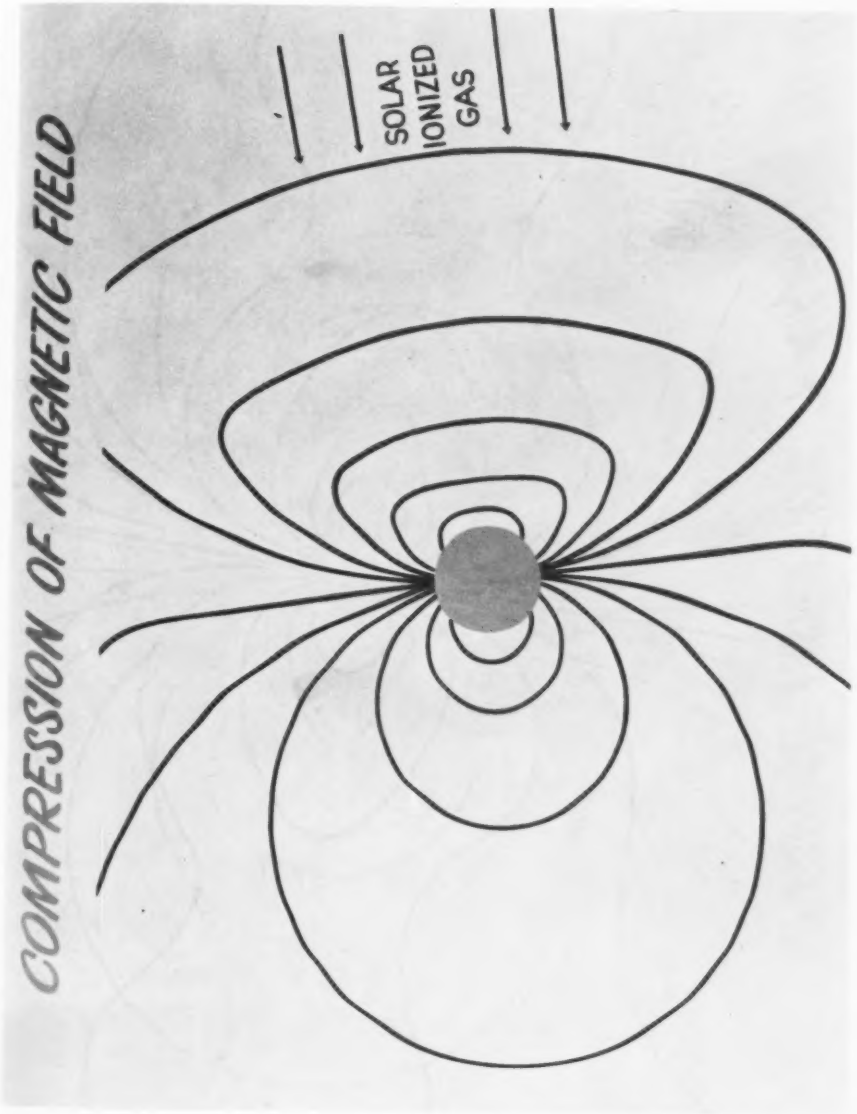
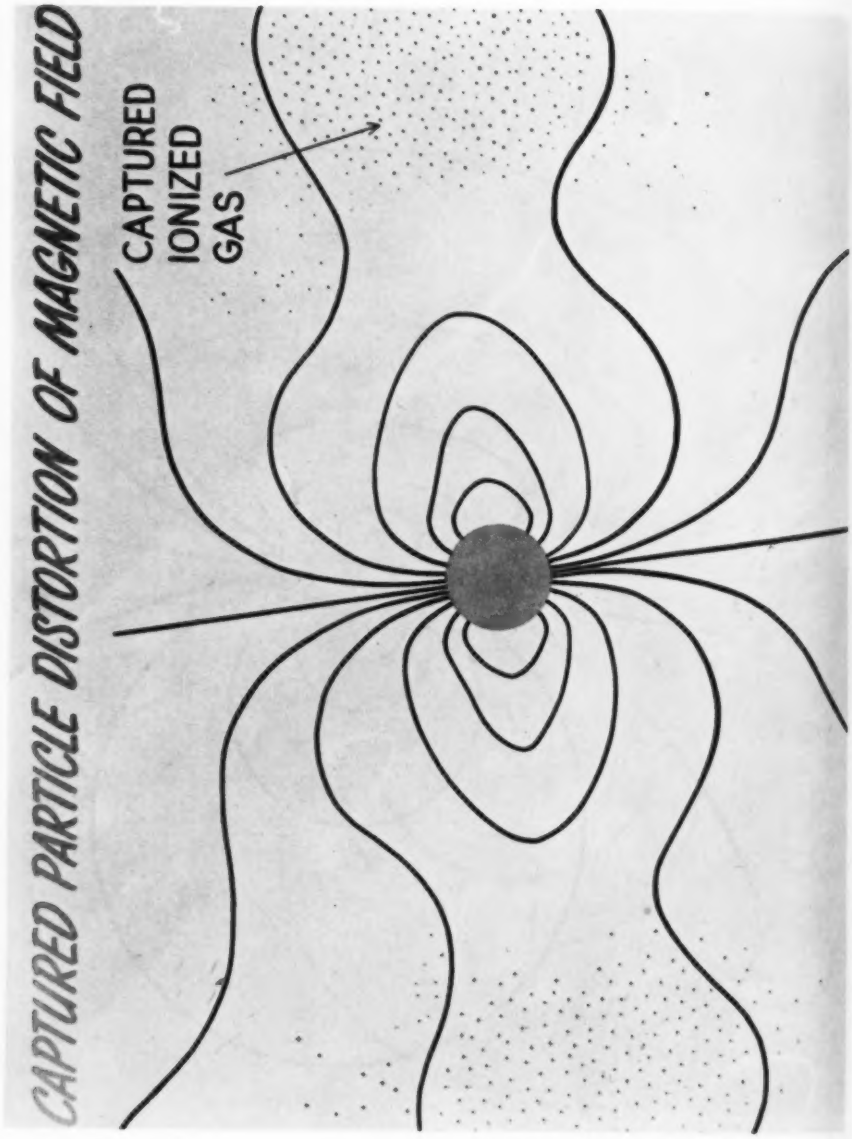

SOLAR IONIZED GAS
COMPRESSION OF MAGNETIC FIELD


CAPTURED PARTICLE DISTORTION OF MAGNETIC FIELD
CAPTURED
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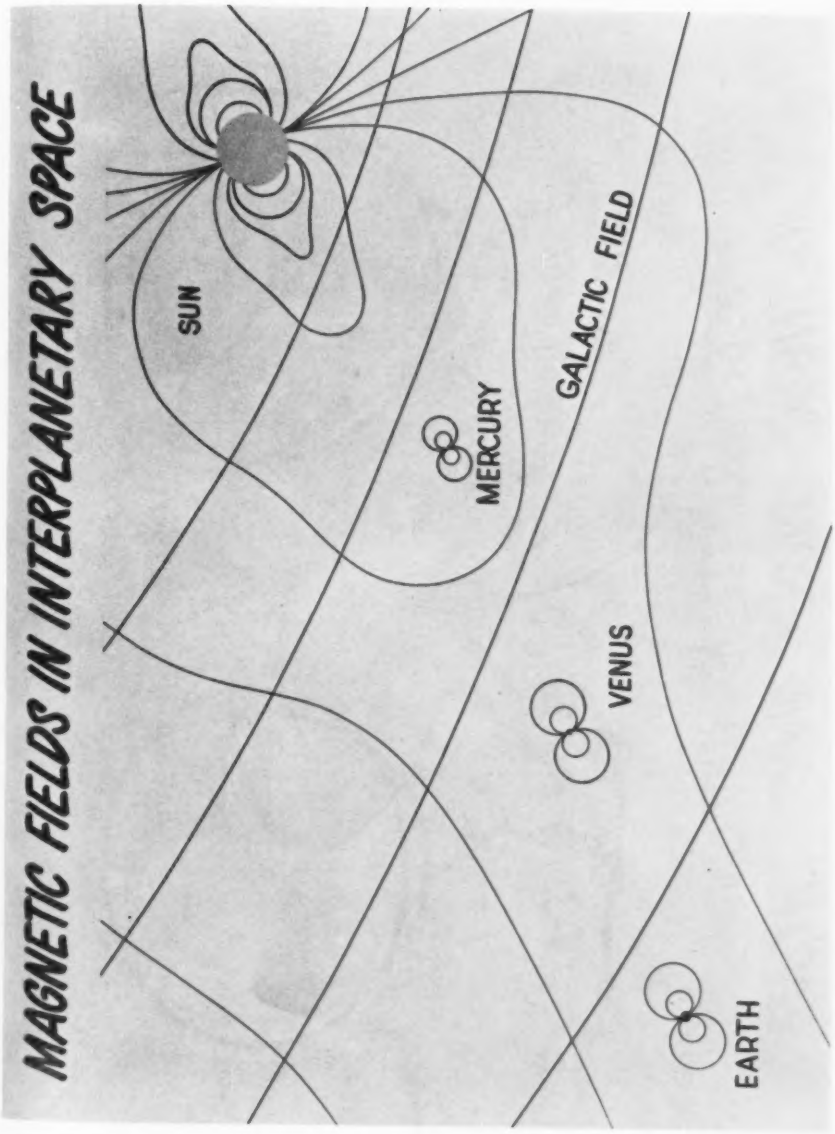
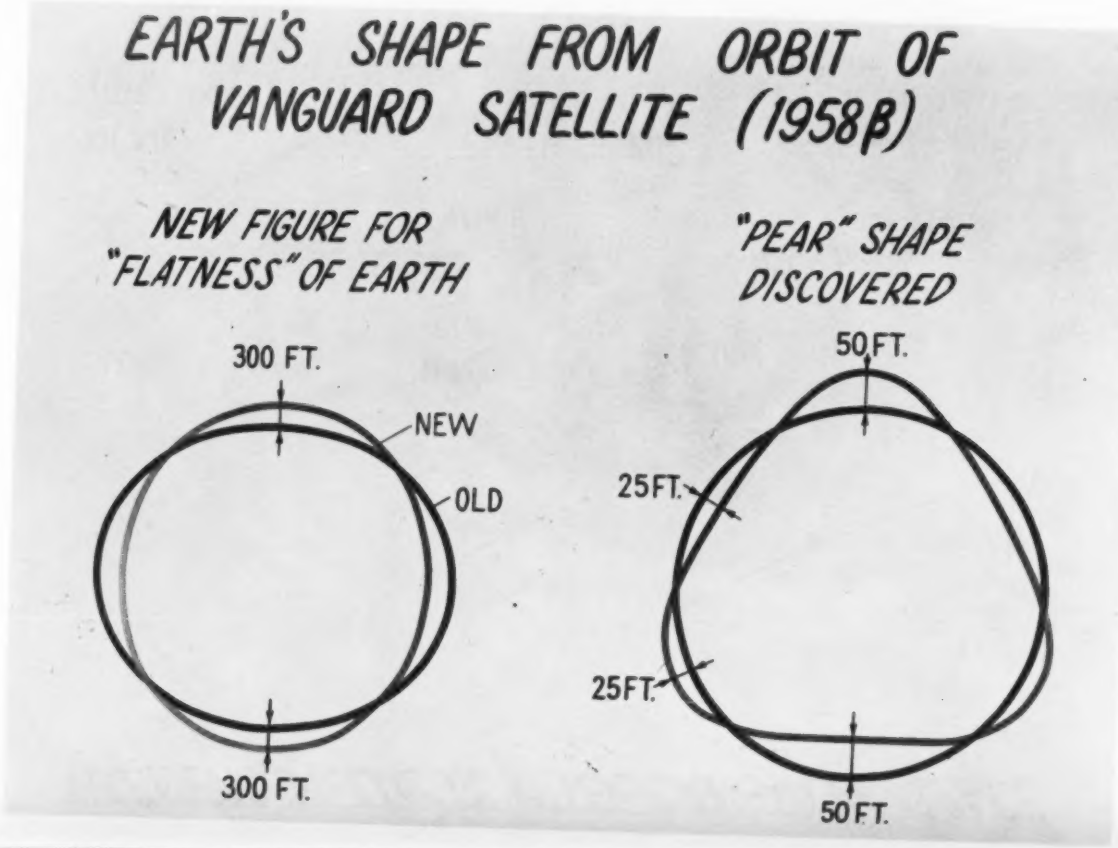
GAS


MAGNETIC FIELDS IN INTERPLANETARY SPACE
SUN
MERCURY
GALACTIC FIELD
VENUS
EARTH


EARTH'S SHAPE FROM ORBIT OF VANGUARD SATELLITE (1958β)
NEW FIGURE FOR "FLATNESS" OF EARTH
300 FT.
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"PEAR" SHAPE DISCOVERED
50 FT.
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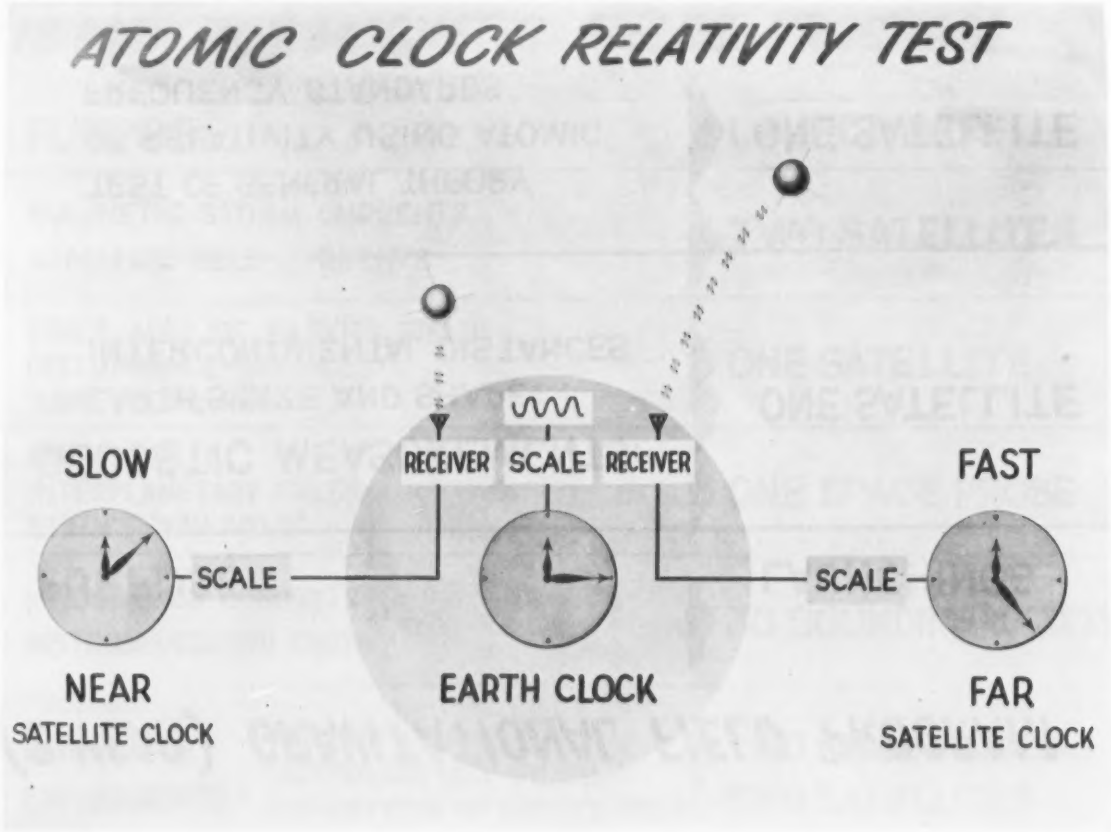
ATOMIC CLOCK RELATIVITY TEST
SLOW
RECEIVER
SCALE
RECEIVER
FAST
SCALE
SCALE
NEAR
SATELLITE CLOCK
EARTH CLOCK
FAR
SATELLITE CLOCK

(2 YEAR) GRAVITATIONAL FIELD PROGRAM

PURPOSE	LAUNCHINGS
GEODETIC MEASUREMENTS: EARTH'S SIZE AND SHAPE INTERCONTINENTAL DISTANCES	ONE SATELLITE
TEST OF GENERAL THEORY OF RELATIVITY USING ATOMIC FREQUENCY STANDARDS	ONE SATELLITE

(18 MONTHS) MAGNETIC FIELDS PROGRAM

PURPOSE		LAUNCHINGS
MAGNETIC STORM CURRENTS RADIATION BELT CURRENTS		TWO SATELLITES
SPACE MAP OF EARTH'S FIELD DISTURBANCE SOURCES WAVE PHENOMENA		ONE SATELLITE
MOON'S FIELD INTERPLANETARY FIELDS EARTH'S "FAR FIELD"		ONE SPACE PROBE
IONOSPHERIC CURRENTS INSTRUMENTATION TESTS		30 SOUNDING ROCKETS
HITCH-HIKE EXPERIMENTS	FIELD OF VENUS INTERPLANETARY FIELDS	TWO SPACE PROBES
	DISTORTIONS OF EARTH'S FIELD	TWO SATELLITES

Senator STENNIS. All right. Thank you very much, Doctor.

Who is your next witness, Dr. Newell?

Dr. NEWELL. The next speaker is Dr. John O'Keefe, who will talk to us about astronomy.

TESTIMONY OF DR. JOHN A. O'KEEFE, ASSISTANT CHIEF, THEORETICAL DIVISION, NASA

Dr. O'KEEFE. Members of the committee, I intend to talk first of all about the general questions which we can investigate by astronomical means, specifically the origin and the size of the universe. Next I intend to talk about the methods for investigating this problem that are especially suitable for a space agency, namely, the investigation of those wavelengths which we cannot see from the ground, and the possibility of seizing particles and examining them physically. Finally, I intend to discuss the long-range and the intermediate program of NASA.

There are two questions in astronomy that are really of fundamental importance for human beings.

ORIGIN AND SIZE OF THE UNIVERSE

The first question is that of the origin, and to some extent also the size of the universe. This is a question that is of a great deal of philosophical importance not only to ourselves, but also to the Russians. A few years ago the Russians were in the habit of calling anybody who discussed these questions an agent of fascism.

At the present time, there is respectable agreement that the age of the solar system—the system of Sun and the planets in which we live—is something like 4½ billion years. Furthermore there is agreement that the galaxy—that is the group of about a hundred billion stars of which the Sun is a member, a group whose profile we see in the Milky Way—has an age of perhaps twice or three times that. But when we go beyond the galaxy to the universe as a whole, which is composed of galaxies, then there is no longer any agreement.

There are two general types of theories about how the universe began. These two theories are very crudely symbolized here. One theory is that about 10 billion years ago, the universe began to materialize as an egg—a small nucleus, extremely hot—in which all kinds of particles reacted with each other. Here that particular mixture of the elements was formed which we now observe. This theory was associated with the name of Lemaitre, and from this theory we can explain in a logical way the expansion of the universe as a blowing up of this egg and the observed gradual retreat of the galaxies in all directions. The other theory was developed by Hoyle, an English physicist; it supposes that the creation of matter goes on all the time. I have tried to represent in a crude way how, according to this theory hydrogen atoms just pop up every so often in space. After enough of them have popped up, they collect into galaxies of this kind, then the galaxies spread out slowly, and finally they disappear into the distance. They go away so far and so rapidly that they can no longer be seen. Under this theory, the elements that we see around us would have been cooked inside the stars.

Let me just stop a minute and talk about that.

Wherever we pick up a sample of material, whether it is from a meteorite or from the stars or from the Earth, we always find that there are certain relationships between the abundances of the elements. Nickel, for example, is always less abundant than iron. Among the different kinds of isotopes of iron there are certain ratios, and those ratios are the same, crudely at least, wherever we get a sample of material.

Now, this can be interpreted in terms of a cooking process or several cooking processes. It is, to speak to you, gentlemen, as if you think of an ax blade which has been heated, and then plunged into water. The experts know from the way they heat the iron what to expect in the way of chemical constitution and physical behavior of the iron after it is plunged into the water. In other words, when you cool a thing suddenly, you freeze the physical and chemical properties of it.

By a nuclear analog of this we can hope to determine which of these two processes was the one which produced the observed element abundance ratios. From the woman's point of view, cooking involves chemical processes which govern the taste and texture and feeling of the material that finally emerges. At least in theory an expert cook could determine from the end product what the temperature was and the lengths of the time during which the cooking took place. Similarly we can hope to attack the question of the original of the universe by an accurate analysis of the abundances of elements throughout the universe, and specifically to find out of these two processes is the one which actually began the universe. I should not say "began the universe," because Hoyle's theory contemplates a universe without a beginning, I should say, by which the elements were formed.

Now, how, actually, are we going to go about learning things like this?

RADIATION IN SPACE

Let us think about the radiation in space. They can be classified according to their wave length. In a certain sense light and X-rays and gamma rays and radiant heat are all forms of radio waves; hence we can classify all of the radiations which reach the surface of the Earth as radio waves of one wave length or another. Light is radio waves of extremely short wave lengths; gamma rays are even shorter, and, of course, there are infrared and heat radiations which are longer.

It is important to see that most of the radiations which exist in space cannot reach us on the ground. At the present time all of our studies have to be made in two areas. The first is the region of visible light, the light by which we see the stars; the other is the region of the radio waves by which, beginning in the time of Jansky and Reber, we have been able to study some of the properties of space.

All other zones here have been denied to us by the Earth's atmosphere. It seems at least possible for us to continue our studies in these areas, by getting above the atmosphere. At the short-wave end we will be receiving gamma rays and X-rays; from these we can logically hope to find out about the corona of the sun and the origin of the cosmic rays, those very powerful radiations which reach the surface of the earth. At the place of their origin, whatever it is, we expect on general physical grounds that gamma rays and X-rays would appear.

Between the region of visible light and the radio gaps, we will have

access to the sort of radiation which tells us about the ordinary reactions which we deal with in ordinary life. It is the region of molecular radiation—we are composed of molecules—and it is the place to ask the more or less earthlike questions. Here Sinton discovered some very faint lines in the spectrum of Mars which seem to indicate there is life there. In this region one can hope to find out what kind of rock is on the Moon by its radiations.

Going over to the long radio waves, we can hope to find the radiations which will tell us about the motion of very large gaseous masses and of the galaxies as a whole. Also perhaps in this region we would be able to find the remotest parts of the universe. These are important in part because of the denial by the dialectical materialists that the universe is bounded.

I don't know whether I have made this point quite clear, but these wave lengths are denied to us on the ground by atmosphere. If we get above the atmosphere we can study what goes on in these wave lengths.

MATTER

The other approach that is appropriate for a space agency is to go out into space and grab some of the material, bring it in, and look at it, and see what the chemical composition is. Through the Van Allen belt probes and through the sending out of space probes we are able to collect samples of cosmic rays which have not been altered by being filtered down through the atmosphere. These give us directly a picture of the average composition of the particle radiations in space.

Looking at the middle range of particle sizes, the meteors and meteorites, we can hope to get hold of a meteor and look at it. It is important to realize that there are meteors that we see going through the summer sky, and there are meteorites in the museum; but it is not certain that these two things are physically the same. We study the passage of the meteors through the sky, and we find that they break as though they were snowflakes; but the things we pick up on the ground are often very solid and hard. If we could capture a few meteors in space and look at them, we would be able to tell a lot more about their meaning than we ever can from studies on the ground.

In particular, the comets are composed, at least in part, of meteors. We are sure of that. We are not sure that the meteorites come from the comets, but we are sure the meteors do; if we could capture a meteor in space we would know a lot more about the physical composition of the comets. Once again it would be a sample of the materials outside, which is important to study the cooking process.

Next there is the possibility of sampling the physical surfaces of the planets, by making a soft landing on one of them and bringing back pieces of it. It would be of the utmost value to have even a single piece, because the explosions which take place on the moon, the formation of the lunar crater is of such violence that it is reasonable to hope that at least occasionally pieces of the moon get thrown down to the surface of the earth. It is quite reasonable to think that there are in our museums samples of lunar surface. It is extremely difficult to be sure which rocks are these samples. If we could have even a small sample of the lunar surface, so that we could identify the other samples then the study of particular objects in our museum could be connected with what we know about the surface of the moon, with an enormous gain in our information.

The point is, of course, that the great difficulty of getting a small sample back, will be fully justified if we can connect together two fields of experience that we already have. We thus gain a great deal. The possibility of connecting up something we know in a museum with something we see through the telescope is one of the great advantages of space exploration.

These are the general items.

FUTURE ASTRONOMY RESEARCH PROGRAM

It is planned to put a telescope up in a satellite and to make it go around the earth and to look in these forbidden frequency ranges. We plan a little bit further on to put a telescope on the moon, where the steadiness of the ground and the freedom from atmosphere means that we can work better than we can in a satellite.

For the immediate program we want to continue the studies from rockets that have been described here today. Here is a picture of the sky, a little bit blurry, resulting from a rocket firing. We see that around Orion, there is a great amount of ultraviolet light. We don't understand how it is produced. Around Spica there is another concentration of ultra-violet light. It is new information, and I just brought it before you as a sample of where we are now. We plan to continue this sort of work, and to explore the nebulosities from the Southern Hemisphere also. We also plan to study gamma rays, the solar ultraviolet and X-rays. We shall study how the X-rays vary in time, how they vary when you go from one frequency to another, how they vary when you go to one part of the surface of the sun to another.

This is our immediate program.

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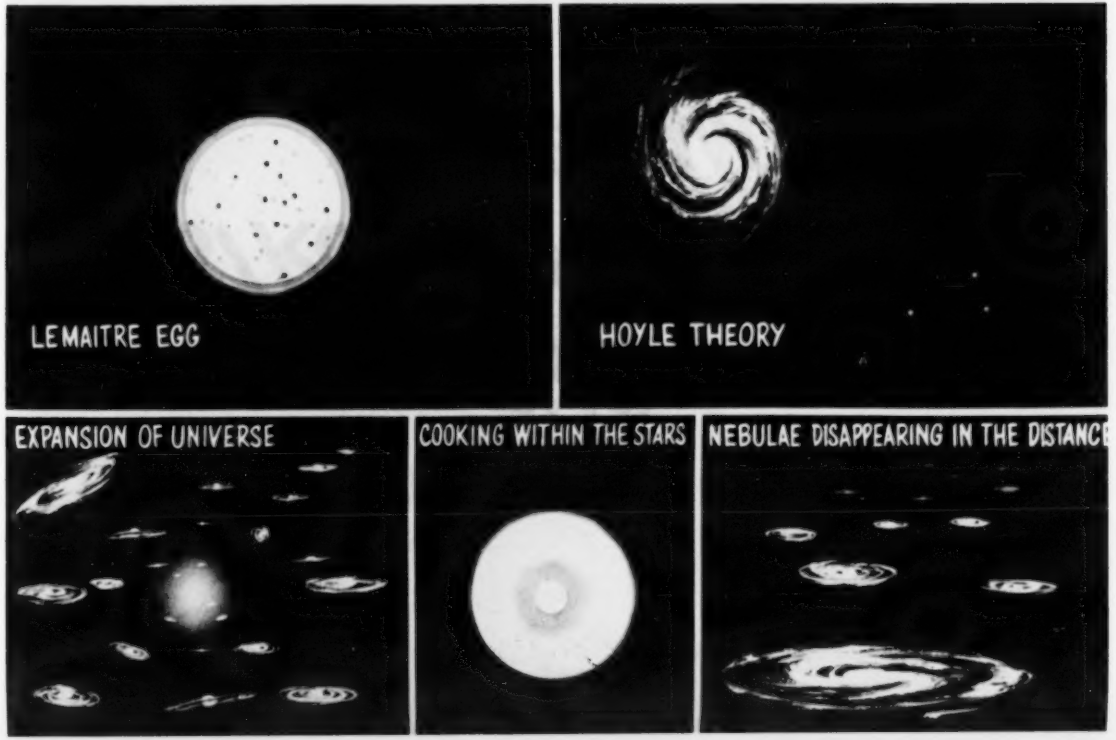
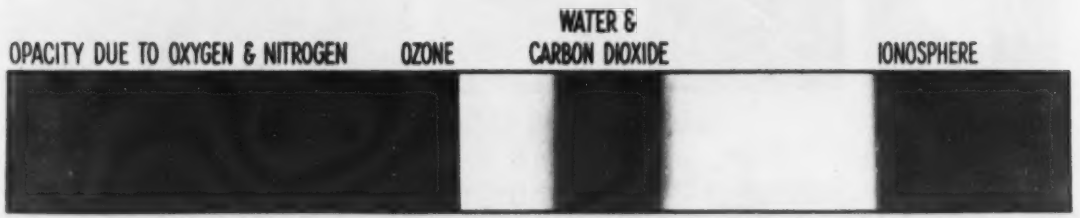
THE ASTRONOMY RESEARCH PROGRAM

THE ORIGIN OF THE UNIVERSE



THE ELECTROMAGNETIC SPECTRUM



PARTICLES IN SPACE
ATOMS
MOLECULES
DUST
MICROMETEORITES
METEOR
METEORITES
CRATER FORMING METEORITES
COMETS
ASTEROIDS
SATELLITES
PLANETS
SUN
10^{-8}
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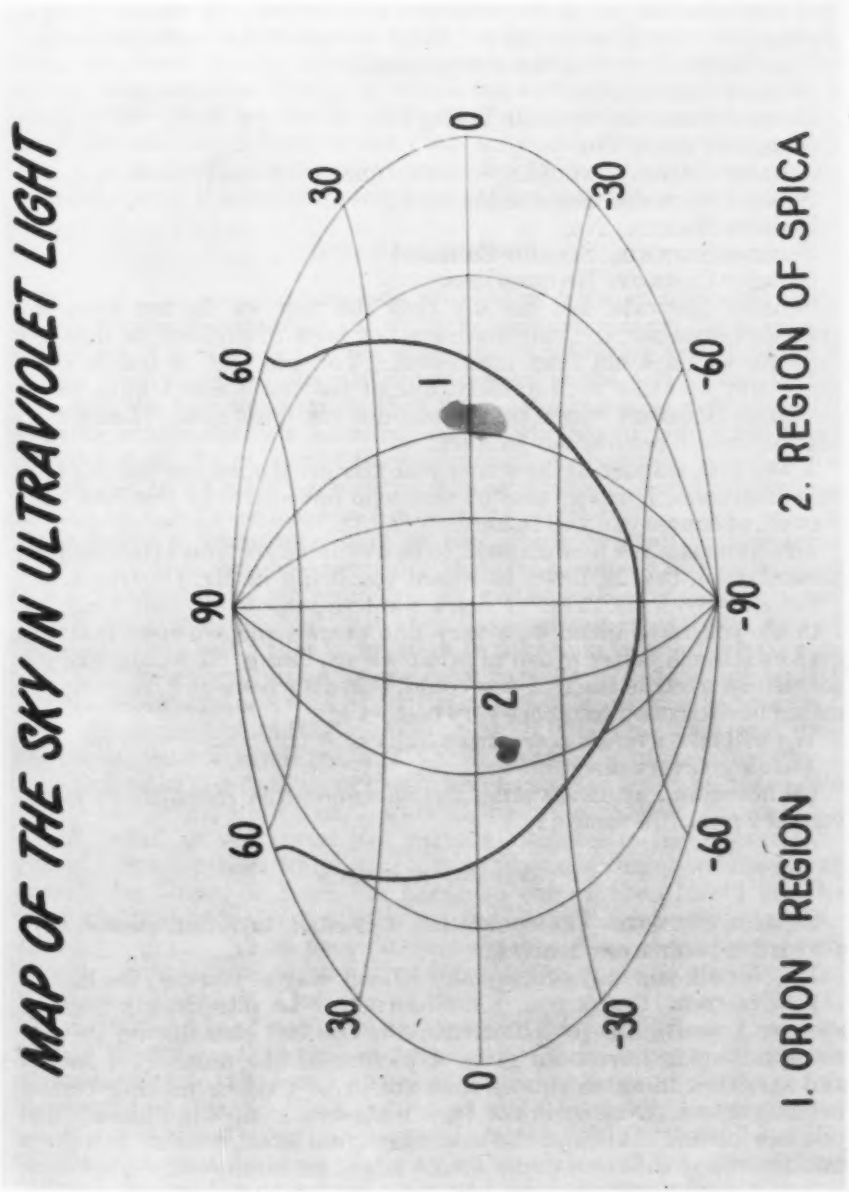
PARTICLE SIZES IN CENTIMETERS


MAP OF THE SKY IN ULTRAVIOLET LIGHT
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2
1. ORION REGION
2. REGION OF SPICA

Senator STENNIS. Doctor, we certainly do thank you. May I confer with the committee now. What is the pleasure of the committee? We had our schedule set up to reconvene at 2 o'clock. If we are going to do that, we should recess now. Shall we take a few minutes here?

Mrs. Smith, do you have some questions?

Senator SMITH. No.

Senator STENNIS. Senator Young?

Senator YOUNG. No.

Senator SMITH. I would need some time to digest a little of it.

Senator STENNIS. Senator Martin?

Senator MARTIN. No.

Senator STENNIS. Senator Cannon?

Senator CANNON. No questions.

Senator STENNIS. Let me say that the fact we do not have any questions does not indicate we have not been impressed, or does not indicate we have not been interested. You just got us out in outer space and we came back quickly, one of the few times I have seen a group of Senators where they could not ask questions. [Laughter.] Maybe we will recover our balance.

I was just wondering how many of you gentlemen are coming back this afternoon, I mean those of you who have already testified. Dr. Newell, of course you will be here.

Dr. NEWELL. We had planned to be available for you after the total presentation, that is, down to where you bring in Mr. Cortright.

Senator STENNIS. Yes. I don't want to impose on your time, but I think you have given us a very fine overall picture here that will give us a much better grasp of what we are doing. I would like you gentlemen to come back, if you could, this afternoon at 2, then we can make the afternoon count the very best way.

We will take a recess now until 2 o'clock.

Thank you very much.

(Whereupon, at 12:30 p.m., the subcommittee recessed, to reconvene at 2 p.m., this same day.)

AFTERNOON SESSION

Senator STENNIS. The committee will come to order, please. We are glad to resume our hearing.

Dr. Newell, you may proceed now in such way as you may see fit.

Dr. NEWELL. Thank you, Mr. Chairman. In introducing the next speaker I would like to call attention to the fact that during the previous talks you have been given a picture of the number of rockets and satellites in space probes that are to be used in making certain investigations. Now it is not legitimate to add up the numbers that you saw on one chart and the next chart, and so on, because in a given satellite many different experiments might be conducted. Therefore, as you saw these things revealed you were seeing repetitions at times.

Mr. Stoller will now provide you with a summary which will give you a correct picture as to the size and scheduling of the program.

Mr. Stoller.

Senator STENNIS. We are very glad to have you here with us. All right, sir, you may proceed.

TESTIMONY OF MORTON J. STOLLER, CHIEF, SPACE SCIENCES PROGRAM, NASA

Mr. STOLLER. I'd like to review for you how sounding rockets, satellites, and space probes complement one another in conducting the science program, the details of which the earlier speakers have been going over. Now we divide our vehicles this way because they turn out to be useful in different areas, that is, we find that sounding rockets will give us certain cross sections in flying their trajectory of the phenomenon of the upper atmosphere and inner space.

SOUNDING ROCKETS

We find that sounding rockets provide us with an opportunity to make instrumentation tests. If we carry instrumentation in the sounding rocket, it is subjected to the same sort of vibration and shock as it will be when launched in a satellite or a space probe, and we can, therefore, test the instrumentation that way. We can also determine by carrying equipment in a sounding rocket whether or not in test cases near the earth the ranges of the instruments are correct, whether the needle will go off scale against the stop or whether it will be down so far that we won't ever measure the quantity of interests.

We define a sounding rocket as one which goes up to about the earth's radius in height—not more than that, some 4,000 miles, and this is a definition of convenience. If we use sounding rockets in our science programs, we find that they have certain limitations, one of the major ones being that if we want to take data over a long time or over a large geographic area we have to make a number of widely distributed firings, and this, of course, gets to be an expensive program.

To supplement sounding rockets so as to cover position and time variations, we use satellites, and I will mention a little later why I have indicated the various orbits in the figure for the satellites. We do use the orbits indicated, highly elliptical, or almost circular, inclined, polar, or equatorial, for various purposes in the science programs. Space probes which will take us from the vicinity of the Earth toward the Moon, or from the Earth to one of the planets are the third class of vehicles we will use for carrying out the complete science program. These provide cross sections of space on the way and give us a sample so we can tell what interplanetary media are like, what the various fields are like, and as the other speakers have explained, the various fields of scientific interest can be explored on the trip. One of the things that we are concerned with in using space probes is the necessity for the development of the technology concerning power supplies, data transmission, and electronic tracking, because these probes are obviously traveling great distances, and if we can't get the data back there is no sense planning on an elaborate instrumentation system. To get the data back we must be able to continuously power the instrumentation on the way. We must have a data transmission system, and, finally, to be able to reduce the data in an analytic way at a later date, we must have some knowledge of where the probe went, and that is where the tracking comes in.

The sounding rocket program is based at the present time on rockets which have been developed over a period of years. Typical of these are the rockets shown on this figure. These were used quite exten-

sively in the IGY program. You can see from the height of the man in the sketch that these rockets run from 25 to 30 feet in height. Nominal payloads and altitudes are indicated—70 miles with 150 pounds of instrumentation for the Aerobee; 165 miles with 150 pounds for the Aerobee-Hi; and 90 miles with 50 pounds for this smaller vehicle, the Nike-Cajun.

Now, these sounding rockets can be pushed to somewhat greater altitudes by reducing the payload. But these altitudes are still not 4,000 miles. And so as part of our program we are making an effort to develop a sounding rocket which is relatively inexpensive, such as this rocket is, or any one of these can be considered to be, for investigations to the 4,000-mile limit. In this way we will be able to go on with relatively routine investigations in an inexpensive way, and we will be able to take our data without the establishment of a large tracking net for this type of measurement. A tracking net will still be required for satellite and space probe work.

SATELLITE ORBITS

We come back to the orbital question for the satellites. The reason we are interested in different orbits is simply that position and time variations are quite important in taking scientific data.

If we successfully inject a satellite into orbit and we have high-quality guidance, we may achieve a circular orbit. The satellite's altitude above the Earth's surface is then essentially constant. In that case we will be able to take data as a function of position at the orbiting altitude in the upper atmosphere or inner space or in far space, depending upon the altitude at which we orbit the particular satellite.

However, more often than not, we won't get a circular orbit because of technological difficulties, and we will try to take advantage of the elliptical orbit by using it to sample in altitude as the satellite moves in and out. We will also take advantage of the fact that one of the properties of the elliptical orbit is that the perigee or the point nearest to the Earth which the satellite attains does not remain fixed in location with respect to the Earth. It tends to move around. So the lowest altitude at which the sample is taken moves around the Earth and the Earth turns inside the orbit, and the net result is that we get samples at different altitudes, at different latitudes, and at different longitudes.

If we can keep the satellite up long enough and keep the power supply working well enough, we can take data over quite a volume of space with one satellite and so get time variations and position variations. Now, the orbital inclination limits the volume of space; that is, if we fire at a given inclination, then it only goes up to, say, 50° latitude and down to 50° latitude. Thus, if we wish to cover the polar regions, we have to have a capability to launch in what are called polar orbits—orbits which go over the poles.

Equatorial orbits are needed for investigating phenomena near the magnetic Equator. By the use of a properly selected orbit, you can adjust your experiment and take the data you are interested in. I might mention two special orbits. One of them is a 63° inclination orbit. With this inclination, the perigee does not move around. It

always stays at the same latitude, so the lowest point is always at the same latitude and the data is then fixed in altitude at a given latitude.

The other orbit that is of interest is one that is at an 83° inclination. This is near polar, and its property is that it moves with respect to the earth at just the right rate so that the satellite will come overhead at the same sun time every day. So if you launch a satellite to come over at 11 o'clock in the morning, at a specific location, it will come over, if it has been launched at the proper altitude, of course, at 11 o'clock every day. This is a special orbit and may have some use in certain experiments.

I would like to review here something that Dr. Newell has already mentioned in his introduction—the grouping of experiments in a given satellite. This is a list of experiments that are typical of those in a satellite that is due to go quite soon in this year. The experiments include instruments to measure X-ray radiation intensity and to measure the Lyman alpha radiation. This latter is solar radiation in one of the bands that Dr. O'Keefe mentioned, that we can't record on the earth's surface. A detector for heavy cosmic ray nuclei is included as are detecting instruments for the earth's thermal radiation and heat balance. You will hear more about this type of instrumentation in the discussion of the meteorological satellite. Instrumentation is also included to measure micrometeorite impacts on the surface of the satellite. There will be equipment to determine the ionosphere's characteristics, and, finally, a technological experiment which measures how the instrumentation equipment itself is performing. This experiment measures how the solar batteries are performing. We use this information so that when we go on to the next satellite or space probe, we will know whether our engineering design data is adequate and has been properly used. If we get performance in agreement with our design, we can go ahead and use the design method again. If the test data indicates that corrections are necessary, the next satellite should benefit from this data.

The satellite appears somewhat as shown in this drawing. There have been some minor changes since the drawing was prepared. At the bottom is where the satellite itself, which has a double cone cross-sectional shape, is attached to the last rocket of the launching vehicle. The satellite has in its center the electronic apparatus for the instrumentation. On the surface where shown are the detectors: the X-ray detector, the Lyman-Alpha detector, the earth's radiation detectors. The antennas come out of this structure after it is in flight. The antennas are reeled out. There are some solar cells in two bands above and below the center of the satellite. These supply power and charge the storage batteries inside the package.

In a satellite of this sort there has been some attention paid to the fact that early experiments indicated that to get a stable spinning satellite—this satellite is to be spun and is supposed to hold its axis position as it goes around the earth by the gyroscopic spin action—that it is better to have the unit as much like a gyroscope wheel as possible rather than like a pencil spinning on its axis. In this case there is relatively thin sheet metal at the outer edge and most of the mass is distributed near the central rim. The spin axis is vertical in the figure.

SPACE PROBES

For space probes we can consider vehicles of this sort for launching, and of course satellites might be launched with these vehicles too. Here we have a capacity to put a payload out to lunar distances or beyond, some 50 to 75 pounds with the Thor-based vehicle with upper stages. With an Atlas-based vehicle 200 pounds of payload can be carried into space.

The type of experiments that are envisioned for these probe vehicles are follow-ons, of course, of the Pioneer I which was launched with the Thor-type vehicle and had a configuration much like the satellite vehicle I just showed you. This gyroscopic wheel type of shape is used here again. These rod elements are the antennas. The Pioneer III units and the Pioneer IV units were of this general shape.

Here again, at the bottom, is the attachment to the final rocket, the payload elements are in here, the electronics and power supply and the optical scan device down here just above the rocket clamp. The point here is that right up here under the tip shroud is the payload and from here on down is the booster vehicle. It takes a lot of booster vehicle to get a small payload out of the effective range of the earth's gravitational field and to the point where you can do a space probe experiment. An early space probe will contain this group of experiments. Here again, instead of just one at a time, a number are carried at once. Here again we measure radiation intensity, cosmic ray energies, micrometeorites, magnetic fields on the way, and electron densities on the way.

In this case we have a chance to measure the astronomical unit. This is a measure of the average distance from the sun to the earth. We have measurements of the relative distances from the sun to the planets, and from the sun to the earth, but we don't have an absolute measure of sufficient precision of how far it is on the average from the sun to the earth.

Tracking a space probe with sufficient precision might improve our data quite a bit. We will measure vehicle temperature on the way for the engineering type of measurement, also the vehicle attitude,

and again we will probably measure how the solar cells and storage batteries perform.

This configuration, which you may have seen in a previous presentation, shows the space probe payload that we were talking about. It is a spherical configuration basically. All instrumentation is on the inside including a set of storage batteries. These affairs which stick out here have on both surfaces large numbers of small solar cells which are connected in such a way as to charge the storage batteries inside. In this way we hope to have a vehicle that will be capable of supplying high power intermittently, and low power continuously for several hundred days while this probe is on its way.

Finally I have tried to summarize how the various vehicles add up when you consider packing the experiments together. In calendar 1959 in the sounding rockets named we come up with some 45 to 50 sounding rocket units. In calendar 1960 some 90 to 100 units. For satellites as presently programed there are eight in calendar 1959 including the Vanguard units which have yet to go, and six in calendar 1960. In space probes two in 1959 and four in 1960.

Now, I think it should be mentioned that in the 1959 and 1960 funding as it is projected, there are also funds which will cover units into calendar 1961 on these programs, that is, there will be additional satellites and space probes in calendar 1961. It will take until calendar 1961 because of the leadtime involved in procurement of boosters and the preparation of payloads, to actually get the advanced probes and satellites into flight. Some of the sounding rockets will also carry over for firing into the next calendar year.

I would like to say in concluding that I think that the science program we have presented represents an effort on the part of NASA personnel, the Space Science Board people who contributed by helping us in programing, and the industrial and university laboratories that will give us a broadly based program, using scientists in this country and in other countries and which will contribute a great deal to our understanding of the world around us. The technological work of 5 or 10 years from now will be based on these basic scientific studies. The knowledge we will gain in this program is basic in nature, and to do an engineering job in the future we are going to need the fundamental information we are gathering now.

SPACE SCIENCES RESEARCH VEHICLES AND PROGRAMMING

SOUNDING ROCKETS

PROVIDE

VERTICAL CROSS SECTION

INSTRUMENTATION TESTS

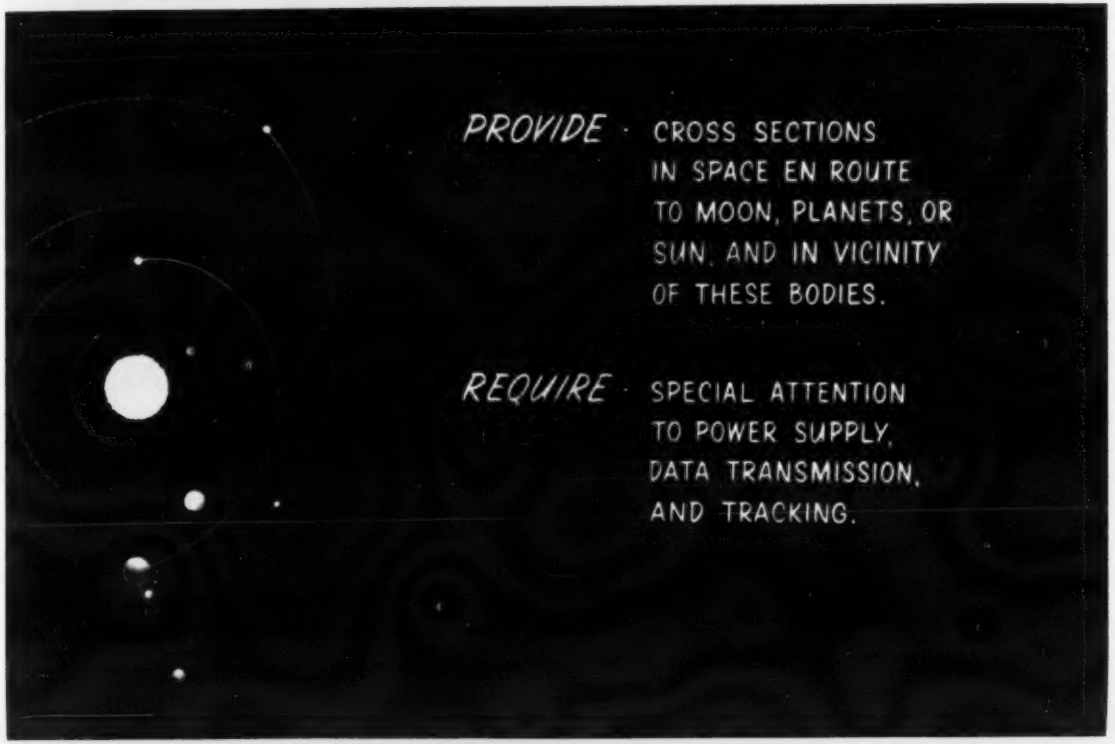
REQUIRE

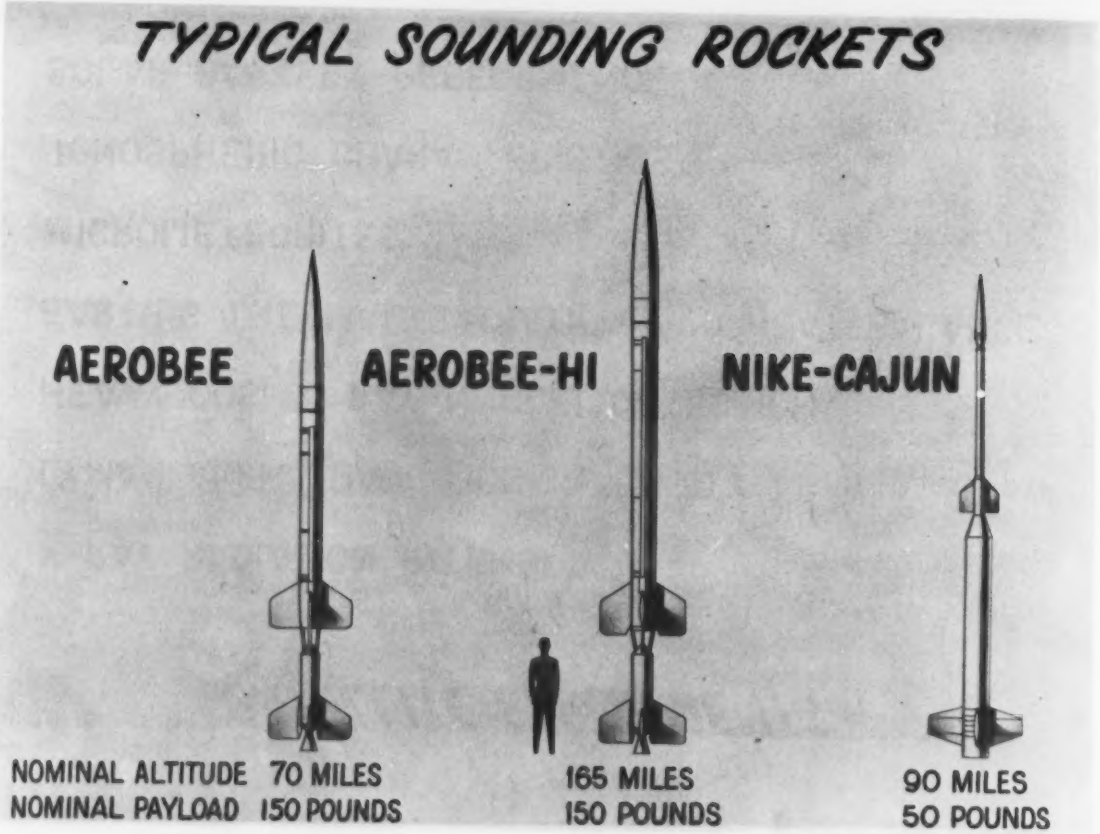
MANY WIDELY DISTRIBUTED FIRINGS OVER AN EXTENDED PERIOD OF TIME

FIRINGS UP TO ONE EARTH'S RADIUS IN HEIGHT (4,000 MILES) ARE CALLED SOUNDINGS

SATELLITES
PROVIDE
POSITION AND
TIME VARIATIONS
ORBITS MAY BE
ALMOST CIRCULAR
HIGHLY ELLIPTICAL
EQUATORIAL
INCLINED
POLAR

SPACE PROBES


PROVIDE · CROSS SECTIONS IN SPACE EN ROUTE TO MOON, PLANETS, OR SUN, AND IN VICINITY OF THESE BODIES.
REQUIRE · SPECIAL ATTENTION TO POWER SUPPLY, DATA TRANSMISSION, AND TRACKING.


TYPICAL SOUNDING ROCKETS
AEROBEE
AEROBEE-HI
NIKE-CAJUN
NOMINAL ALTITUDE 70 MILES
NOMINAL PAYLOAD 150 POUNDS
165 MILES
150 POUNDS
90 MILES
50 POUNDS

SATELLITE EXPERIMENTS

X-RAY RADIATION INTENSITY

LYMAN ALPHA RADIATION INTENSITY

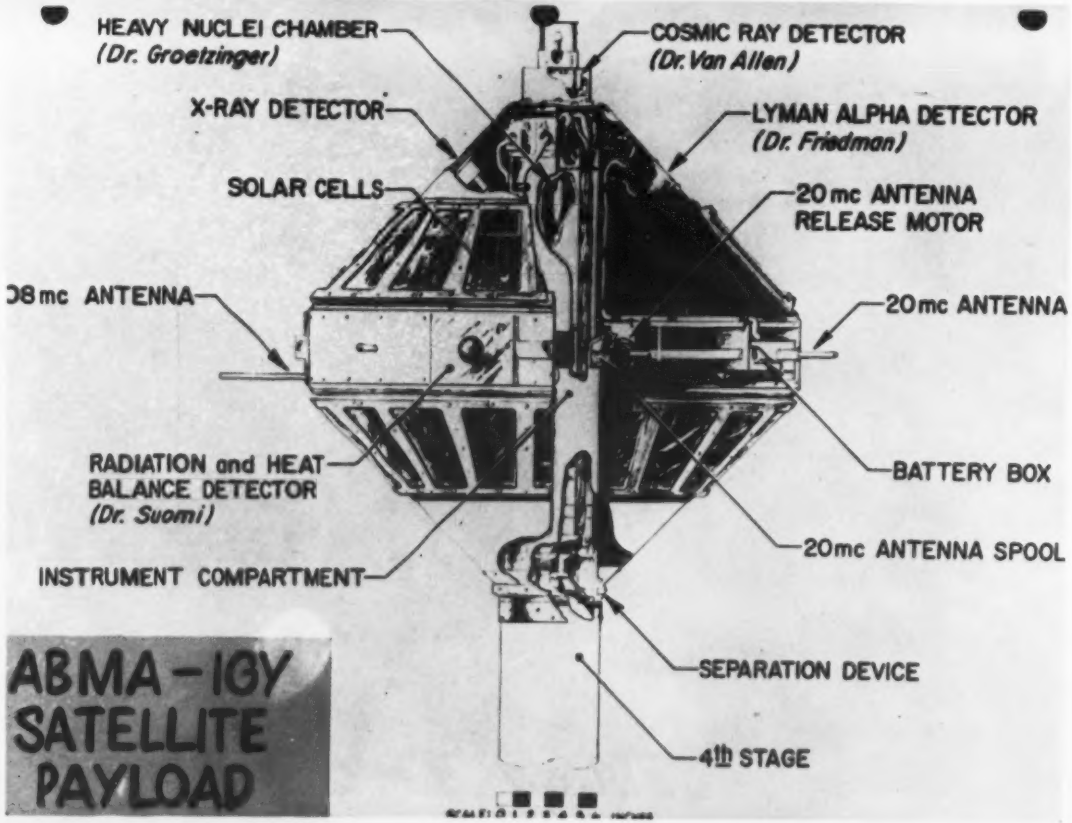
HEAVY COSMIC RAY NUCLEI DETECTION

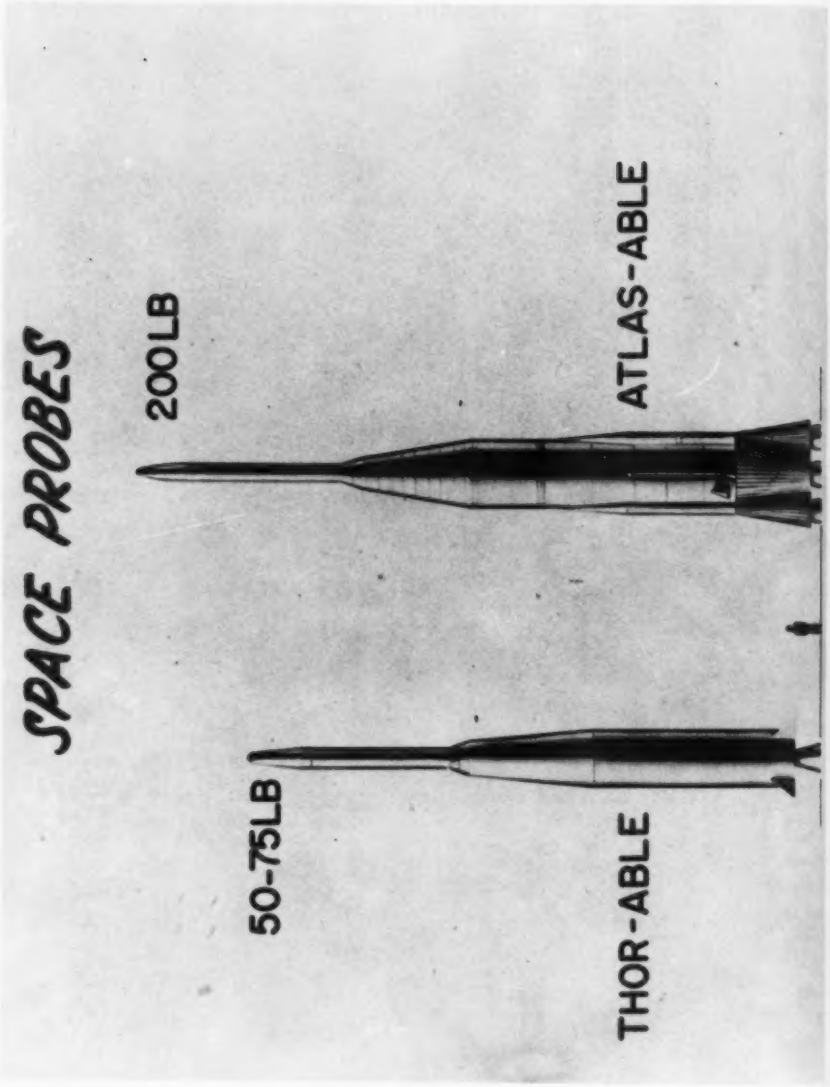
EARTH'S THERMAL RADIATION AND HEAT BALANCE

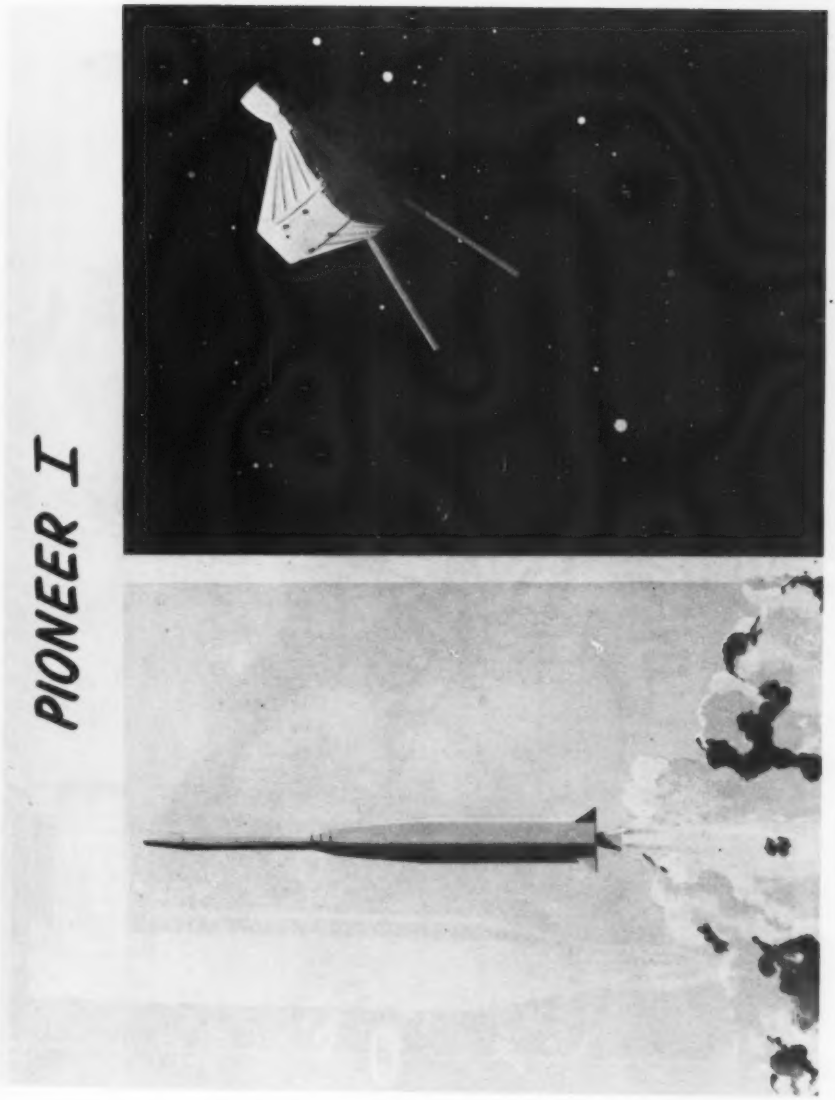
MICROMETEORITES

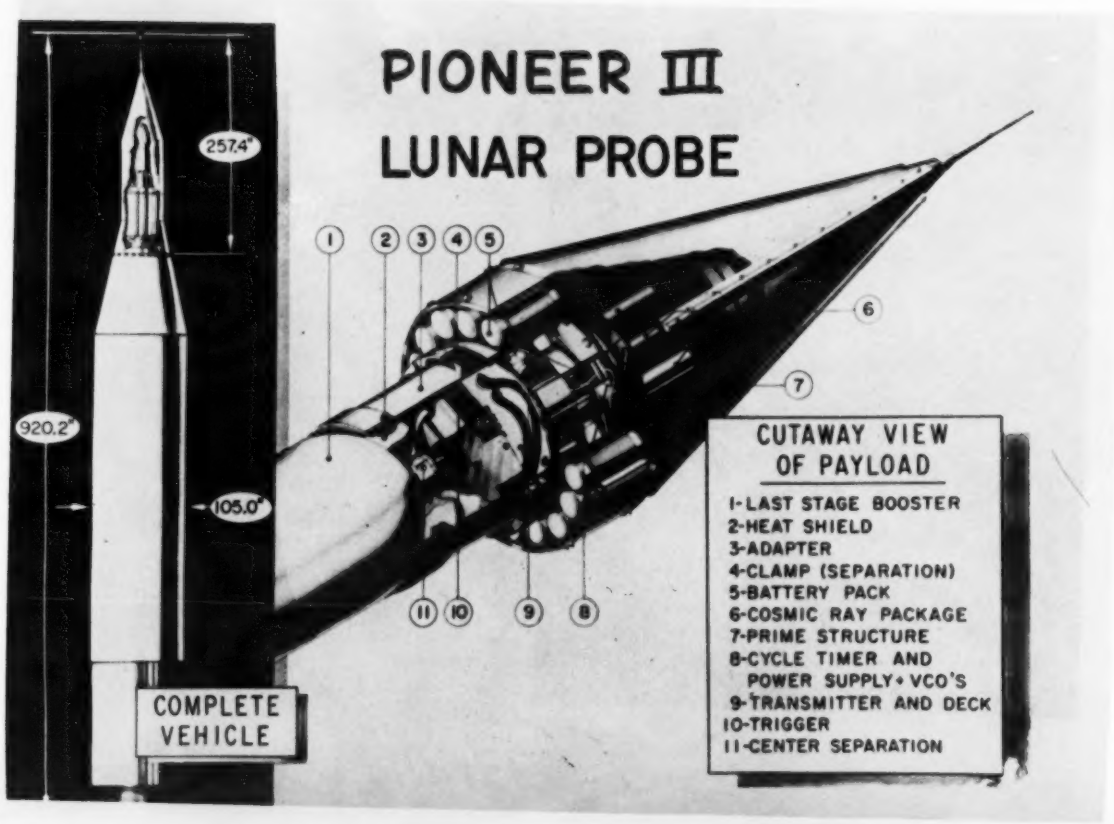
IONOSPHERIC CHARACTERISTICS

SOLAR BATTERY PERFORMANCE


HEAVY NUCLEI CHAMBER
(Dr. Groetzinger)
COSMIC RAY DETECTOR
(Dr. Van Allen)
X-RAY DETECTOR
LYMAN ALPHA DETECTOR
(Dr. Friedman)
SOLAR CELLS
20 mc ANTENNA
RELEASE MOTOR
108 mc ANTENNA
20 mc ANTENNA
RADIATION and HEAT
BALANCE DETECTOR
(Dr. Suomi)
BATTERY BOX
20 mc ANTENNA SPOOL
INSTRUMENT COMPARTMENT
SEPARATION DEVICE
4th STAGE
ABMA - IGY
SATELLITE
PAYLOAD


SPACE PROBES
200LB
50-75LB
ATLAS-ABLE
THOR-ABLE


PIONEER I


PIONEER III
LUNAR PROBE
257.4"
920.2"
105.0"
COMPLETE VEHICLE
1
2
3
4
5
6
7
8
9
10
11
CUTAWAY VIEW OF PAYLOAD
1-LAST STAGE BOOSTER
2-HEAT SHIELD
3-ADAPTER
4-CLAMP (SEPARATION)
5-BATTERY PACK
6-COSMIC RAY PACKAGE
7-PRIME STRUCTURE
8-CYCLE TIMER AND POWER SUPPLY + VCO'S
9-TRANSMITTER AND DECK
10-TRIGGER
11-CENTER SEPARATION

EXPLORATORY EXPERIMENTS IN EARLY SPACE PROBES

RADIATION INTENSITY

COSMIC RAY ENERGIES

MICROMETEORITES

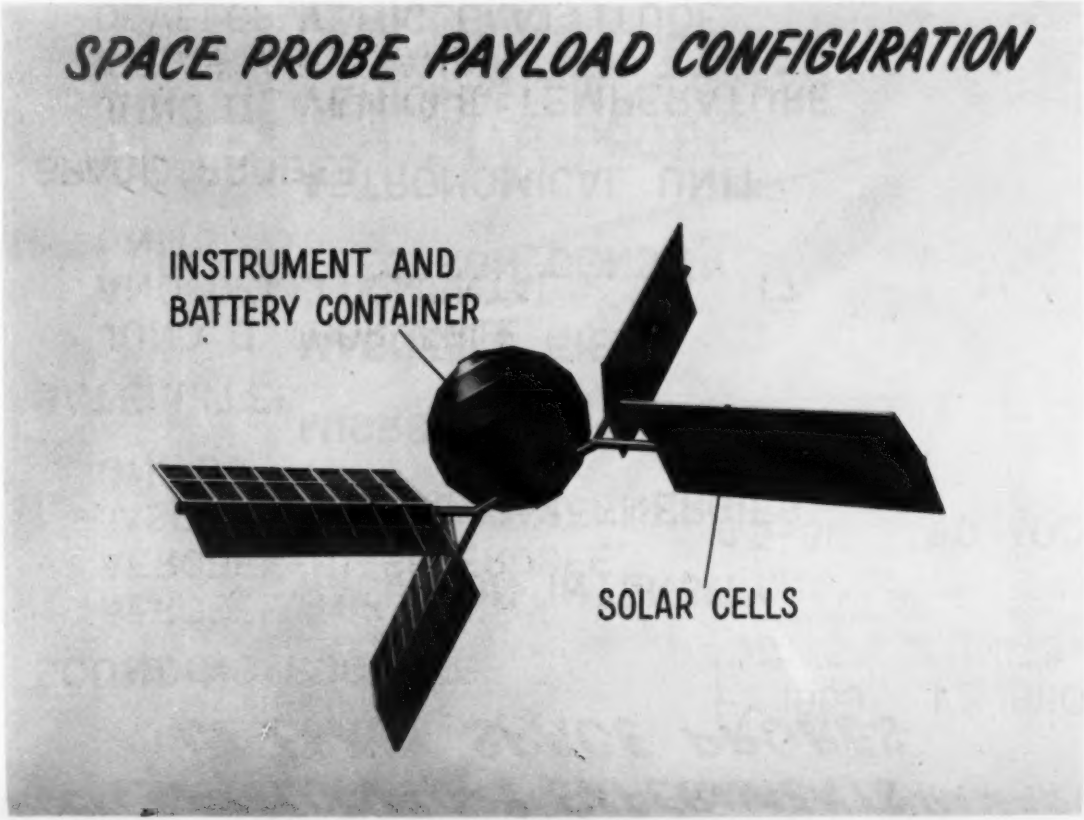
MAGNETIC FIELD

ELECTRON DENSITY

ASTRONOMICAL UNIT

VEHICLE TEMPERATURE

VEHICLE ATTITUDE


SPACE PROBE PAYLOAD CONFIGURATION
INSTRUMENT AND
BATTERY CONTAINER
SOLAR CELLS

ROCKET, SATELLITE & PROBE VEHICLE SUMMARY

	FY 1959 UNITS	FY 1960 UNITS
SOUNDING ROCKETS		
AEROBEE, NIKE-ASP, AEROBEE-HI, SPAEROBEE, JASON AND DEVELOPMENTAL UNITS.	45-50	90-100
SATELLITES		
JUNO II, THOR-ABLE AND DEVELOPMENTAL UNITS.	17	18
SPACE PROBES		
JUNO II, THOR-ABLE, ATLAS-ABLE, AND DEVELOPMENTAL UNITS.	4	7

Senator STENNIS. Thank you very much, Mr. Stoller. That completes your statement. All right, Doctor?

Dr. NEWELL. In the next talk, Mr. Crocker will review for you an illustrative example of our look toward the future.

Much of what you have heard described before has been based on present activities and activities in the immediate future, but we must continue to look beyond.

Mr. Crocker.

Senator STENNIS. All right, Mr. Crocker, we are glad to have you, sir. You proceed in your own way.

TESTIMONY OF J. ALLEN CROCKER, CHIEF, GUIDANCE AND CONTROL PROGRAMS, NASA

Mr. CROCKER. Mr. Chairman and members of the committee, this presentation is on advanced lunar and planetary exploration. For the purpose of tying this to the talks which you have already heard, yesterday you heard about engines, propulsion systems. This morning and immediately after lunch you heard about scientific payloads. The effort here will be to tie these together in providing the vehicle which gets the payload to the point where you want to use it, and I will give you some idea of the weights which might be involved in these vehicles.

LUNAR EXPLORATION PROGRAM

This first chart presents a program of lunar exploration starting with today's capability as we have inherited it from the ballistic missile community in regard to booster performance and guidance accuracy, and progresses through a series of missions of increasing demands on booster performance and guidance accuracy.

This first mission, the near miss of the moon, has been described by Mr. Stoller from the scientific viewpoint. It is of interest that the last of the moon probes, Juno IV or rather Pioneer IV which was fired on March 3, 1959, performed exactly as was programed as far as the first stage booster was concerned. However, the upper stage, solid rocket units each burned about one second longer than was programed, and this meant that more weight was carried for a longer period of time than was intended. The added drag then resulted in an injection of the payload after booster burnout of about 188 miles an hour slower than was intended, and about 11¼ miles lower in altitude than was intended.

Now the positioning of this payload in space depended entirely upon the guidance that would be used with a ballastic missile; in other words the guidance in only the first stage of this series of rockets. As you know, Pioneer IV missed the moon by 37,000 miles. It did, however, become a satellite of the sun.

Under our feeling of urgency we find that a direct impact on the moon offers some elements of attractiveness. For that reason the types of experiments which might be performed as you approach the surface of the moon and the kinds of instruments which can be designed and built to withstand impacts of the velocities of the order of 7 to 9,000 feet per second and continue to operate after these impacts are being examined.

USE OF THOR-DELTA IN UNMANNED ORBITERS

The guidance available for the Thor-Delta is accurate enough to have this missile contact on the moon. It would carry an estimated 100-pound load. If we take part of that 100-pound load and use it, that is, assign it to a retrorocket, then we can slow down the forward motion of this payload and lessen the impact and give the instruments a better chance of operating after contact with the moon.

In the upper left corner of this poster we have an outline of a possible payload. You see an aerodynamic shape here which is intended to get the payload through the earth's atmosphere and once above the earth's atmosphere this external shroud would be thrown off, and then the front of this would be this fainter outline which you see, which is the retrorocket. As you approach the surface of the moon, this rocket could be fired by earth command, and if you find that there is a trajectory which would permit this spin stabilized longitudinal axis to come along a radius of the moon toward the moon instead of coming at some askewed angle, if there is such a trajectory, then you could utilize this procedure to slow the payload down on approach.

Under those circumstances this darker outline, which is the payload here with a penetrating spike, could be used to do work as it makes contact on the surface of moon and absorb the energy which is remaining. It is believed that instruments can be designed which would perform after such an experience.

The same vehicle, the Thor-Delta, which has just been described here can be used for unmanned orbiters, and it would be an easier task to place an orbiter around the moon than to go through this impact that I have just outlined. The reason that I say it would be easier is that one could wait as the vehicle goes past the moon until its axis is in the right direction to establish the satellite orbit, so that you are not restricted in your approach as you are in the case of the impact. You would need the retrorocket in order to slow down the velocity and bring it to a proper value for a satellite orbit. For that reason you see that the payload weight has been reduced to a 65-pound useful load where the remaining 35 pounds is in the retrorocket. When we come to the development of the Vega, which you heard about yesterday, we can carry much larger payloads. It is reasonable to assume that unmanned orbiters will be desired and used for a long period of time.

ROUGH AND SOFT LANDINGS ON THE MOON

The next item here, rough landings, could be accomplished with either the Thor-Delta, the same vehicle we have been talking about, with the 50-pound payloads, or with the Vega carrying 650-pound payloads. This object in the center of the poster is a concept of a rough landing approach. The idea here is that this sphere would be made of material of low coefficient of restitution so that when it makes contact with the surface of the moon energy of that contact would be absorbed in deforming this outside package, and the interior part here, which contains the scientific instruments, would receive less of a shock and would be more likely to work.

Soft landing could be made moderately soon with the Vega or the Atlas-Centaur with 430-pound payloads or 730-pound payloads re-

spectively, and when the Juno V and the Nova come along, then we can carry payloads of thousands of pounds for such missions. The purpose of a soft landing mission is to position scientific instruments wherever the scientists tell us they want them on the surface of the moon.

This is the first mission listed which places a requirement for terminal guidance. This guidance differs from the guidance that we have used in launching the vehicle from the surface of the earth in that this now functions to orient the vehicle as it approaches the moon, and controls its actions up to the time that it makes contact on the surface. Soft landing missions place the requirement for attitude control of the vehicle as it approaches the moon, a requirement for a retrorocket to cancel the forward velocity of the vehicle, a requirement for the ability to maneuver above the surface of the moon so that you can select your point of letdown, and some means of absorbing the final shock of contact.

Illustrated in the lower left side here is the concept of a soft landing vehicle and shown is the retrorocket as this is coming towards the surface of the moon. You see here spider legs which would permit the vehicle to set down on a uneven surface. These spider legs would then stretch steel cables and absorb the final energy of contact.

UNMANNED ORBIT AND INSTRUMENT RETURN

The next missions which are listed place added requirements of returning to the earth, reentering the earth's atmosphere and recovering the contents of the vehicle after it has been launched. The right hand corner here shows a vehicle taking off from the surface of the moon, and you will notice that the retrorocket and spider leg configuration which was used in the soft landing approach here, which was so necessary when you came down on a planet where there was no atmosphere to help you ease your way down, has been left behind in order to give the maximum payload for the return trip to the earth. This material which is left behind also can serve a usefulness as a launching platform for that return journey. The Juno V is probably the vehicle which could be used in this circumstance, a 200-pound payload coming back to the earth.

MANNED LANDINGS AND RETURN

Ultimately, but probably not before the passing of the next decade, there will be manned landings on the moon. These will have to await for the development of the Nova which you heard about yesterday, and it might appear at first glance that this 2,100-pound payload for return to earth is somewhat marginal for assigning man to this mission.

However, we can help ourselves by sending in advance other loads and positioning them with subsistence and technological supplies so that man can support himself when he arrives at the moon.

INTERPLANETARY PROGRAM

This slide shows a program of interplanetary probes and it starts with less difficult and progresses through more difficult missions, hoping to keep pace with the development of vehicles, that is, engines, midcourse guidance and long distance communication capabilities. This series of missions is already underway. Referring back to Pioneer IV which I mentioned earlier, this was actually tracked, to a distance of 406,000 miles. At that time the batteries which power the transmitter became exhausted so we lost contact with the probe. This is a distance which is 32,000 miles further than any object has ever been tracked, the nearest rival being the Russian satellite, Mechta.

FUTURE SPACE PROBE PROGRAM

The mission first tabulated here, space probes, refers to the Thor-Able and Atlas-Able with 50- and 200-pound payloads that Mr. Stroller described in the earlier talk as being authorized for this year, and they are programed for this summer. Ultimately the Vega would be able to carry 1,300-pound payloads in such missions. The Venus and Mars near misses also could be accomplished by the Vega vehicle with the same kind of payload, 1,300 pounds.

In the case of the orbiters we have the Earth and Venus in August of 1962 which would be a possible date for a launch. And again 150 days later the Earth and Vensus in the relative positions at the time that the satellite acquired the planet. The problem here is one of the guidance, the variety of commands that you have to issue, actually getting the proper velocity at the proper time to orbit this planet, and the communication path of many millions of miles from Earth to Venus.

Scientists are already thinking of going beyond the planets, Venus and Mars. You have heard this morning about desires to go to Jupiter in one direction. The Juno V is probably the first vehicle which would carry payloads adequate to make such a mission, that is so costly and so time-consuming, worthwhile. And in the other direction going past Vensus toward the sun also requires a booster of terrific thrust.

The manned landings are very definitely in the future. Ahead of manned landings there will probably be instrumented landings to learn about how hostile the environment is and what we might expect. But manned landings will probably not be attempted until we have a capability of fabricating structures or vehicles in space.

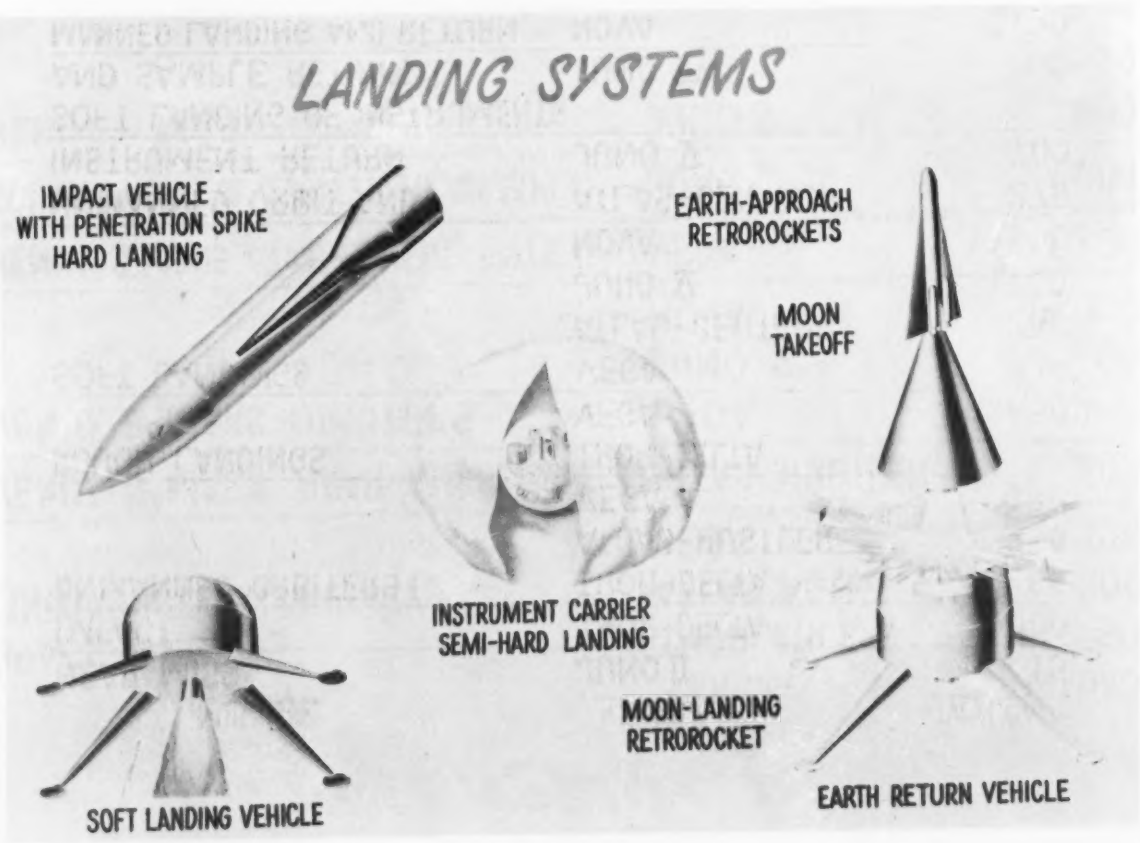
In conclusion then the missions going to the Moon and into space which have been reviewed have as their objectives the development of technology in the six areas communications, propulsion, instrumentation, guidance, reliability, and design data. The initial emphasis has been on propulsion and reliability, and the remaining areas are just beginning to receive attention.

LUNAR AND PLANETARY EXPLORATION

LUNAR EXPLORATION

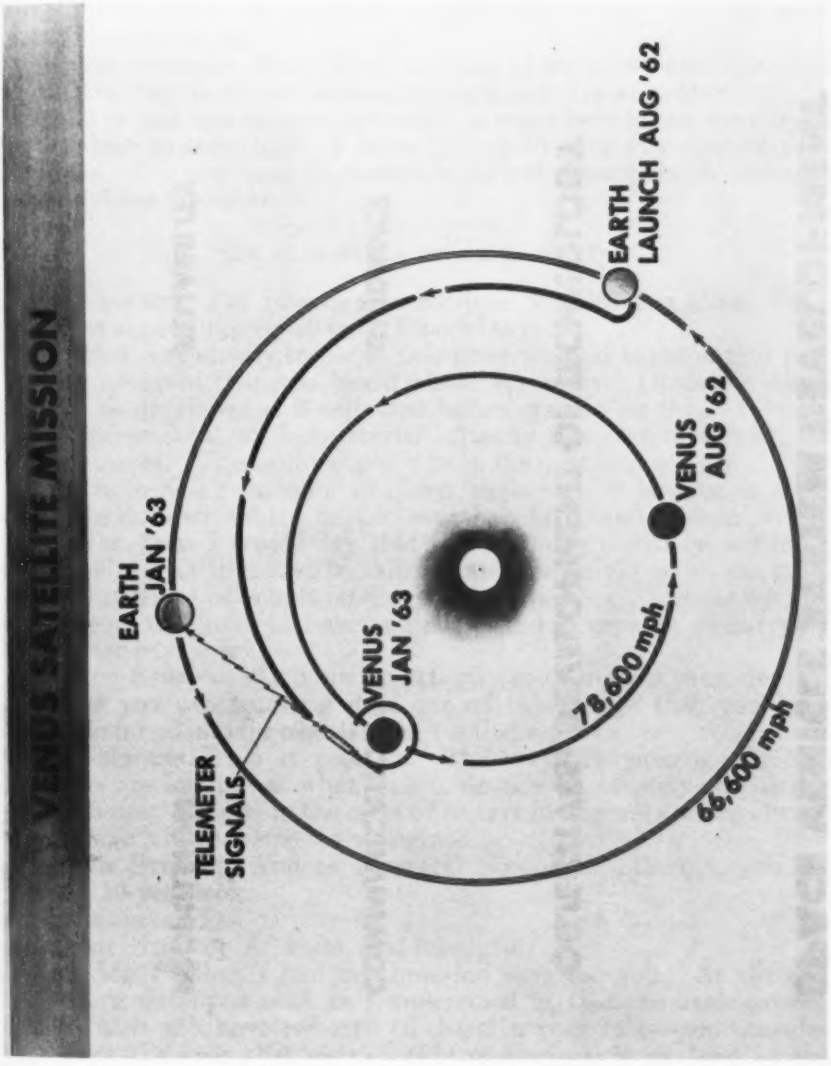
MISSION	VEHICLE	PAYLOAD
NEAR MISS	JUNO II	15
IMPACT	THOR-DELTA	100
UNMANNED ORBITERS	THOR-DELTA	65
	ATLAS-HUSTLER	250
	VEGA	980
ROUGH LANDINGS	THOR-DELTA	50
	VEGA	650
SOFT LANDINGS	VEGA	430
	ATLAS-CENTAUR	730
	JUNO V	1,700
	NOVA	19,900
UNMANNED ORBIT AND INSTRUMENT RETURN	ATLAS-CENTAUR	275
	JUNO V	700
SOFT LANDING OF INSTRUMENTS AND SAMPLE RETURN	JUNO V	200
MANNED LANDING AND RETURN	NOVA	2,100

MANNED LANDING AND RETURN	NOVA	2,100



INTERPLANETARY PROBES

MISSION	VEHICLE	PAYLOAD
SPACE PROBES (INITIAL INTERPLANETARY)	THOR ABLE	50
	ATLAS ABLE	200
	VEGA	1,300
VENUS & MARS NEAR MISS	ATLAS HUSTLER	200
VENUS & MARS ORBITERS	VEGA	260
	JUNO V	900
	NOVA	15,000
VENUS & MARS ATMOSPHERE ENTRY	VEGA	1,300
SOLAR PROBE & JUPITER NEAR MISS	JUNO V	1,900
VENUS & MARS LANDING	JUNO V	400
	NOVA	4,500


VENUS SATELLITE MISSION
EARTH LAUNCH AUG '62
VENUS AUG '62
EARTH JAN '63
VENUS JAN '63
TELEMETER SIGNALS
78,600 mph
66,600 mph

SPACE VEHICLE SYSTEM DEVELOPMENT

OBJECTIVES: DEVELOPMENT OF TECHNOLOGY

COMMUNICATIONS

GUIDANCE

PROPULSION

RELIABILITY

INSTRUMENTATION

DESIGN DATA

Senator STENNIS. Thank you very much, sir. We may get back to you in a few minutes. Dr. Newell, you call the breaks for questions now when you think they should come.

Dr. NEWELL. This concludes the first section on space science. The next section of talks on space vehicle applications would be conducted by Mr. Cortright. It might be appropriate to stop here for questions if you so desire.

Senator STENNIS. Yes. Well, let's see if we have some questions now; Mrs. Smith, do you have any questions? Senator Martin?

There is just one matter that came to mind here about your lunar exploration presentation. I know you can't give any specific data on dates. Do you want to undertake to put some possible dates on some of those projects?

TEN YEAR SPACE PROGRAM OUTLINE

Mr. CROCKER. The program as outlined was looking ahead for a period of approximately 10 years I would say.

It is tied very closely to the vehicle program that is the engine propulsion program that you heard about yesterday. Obviously those have to be developed and delivered before we can do this. I would say, however, that we have started already the near miss with the Pioneer series. The following will be in the next year or two.

We are thinking in terms of direct impact; if it is done at all it should be done within the next 18 months. If it can't be done within 18 months, then I would say that the technology will be advanced to the point that it should be skipped and we should go to the more difficult missions of rough landings or soft landings, because by that time we should hope to have engines that are capable of carrying the heavier payloads.

Senator STENNIS. As I understand it, your engines may develop to where you can leapfrog over one of these steps that you have outlined and go into the next landing; is that right?

Mr. CROCKER. This is possible. The way the program is outlined, we are looking at what we can do now or as early as possible trying to keep one eye on the state of the art in engines and we always have to match the payload to the engine.

Senator STENNIS. And as a general proposition, though, you are taking a 10-year look.

Mr. CROCKER. Yes.

Senator STENNIS. All right, that is helpful.

Now, Mr. Stoller, I had one question here for you. At the end of your remarks you said, as I understood it, that the basic experiments which you have referred to there in your talk—you consider they were the ones that carried this real scientific payload in the future developments—that a great many different programs could be based upon these projects you outlined; is that right?

Mr. STOLLER. Yes, sir.

Senator STENNIS. Restate that if you will.

Mr. STOLLER. The program that was outlined on the last chart covers essentially those rockets, satellites, and probes associated with the science program that was discussed earlier today.

The vehicles for use in, say, meteorology and communications and other purposes such as man in space will be discussed by the others.

DESIGN DATA
INSTRUMENTATION

Now the second part of it was that I think that it is this basic science work, that investigation into the things that we have to get some firsthand information on to verify theoretical studies that have been made by people working you might say just off with their books, the experimental studies that we can make with these vehicles are going to give us the basic pieces of information from which the new technology will grow.

If we don't have our basic library of information to start with, we won't have any advanced engineering 10 years from now.

Senator STENNIS. That was the main point that I was interested in. Thank you, sir. If there are no other questions, Doctor, you may proceed.

Dr. NEWELL. We have a new group here to take over. They were not the group this morning when we were sworn in.

May I introduce Mr. Edgar Cortright who will take my place here?

Senator STENNIS. All right, thank you very much. Come around, Mr. Cortright. If you will call the names of the gentlemen now who are going to testify, under your direction, I will ask them to please stand and be sworn as a group.

Mr. CORTRIGHT. Dr. Harry Wexler, Mr. Benjamin Milwitzky, Mr. Leonard Jaffe.

Senator STENNIS. Stand up, please, gentlemen. Is that all?

Mr. CORTRIGHT. Yes.

Senator STENNIS. Will you gentlemen hold up your hands? Do you solemnly swear that your testimony before this committee will be the truth, the whole truth, and nothing but the truth, so help you God?

Mr. CORTRIGHT. I do.

Dr. WEXLER. I do.

Mr. MILWITZKY. I do.

Mr. JAFFE. I do.

(The biographical sketches of the witnesses follow:)

EDGAR M. CORTRIGHT, CHIEF, ADVANCED TECHNOLOGY PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Edgar M. (Maurice) Cortright was appointed chief of the advanced technology program in the Office of the Assistant Director for Advance Technology when the National Aeronautics and Space Administration was established on October 1, 1958. Before joining the NASA headquarters staff, he was Chief of the Plasma Physics Branch at the Lewis Laboratory, in Cleveland, Ohio.

Cortright joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, as an aeronautical research scientist on the staff of the Lewis Laboratory in 1948. From 1949 to 1954, he was Head of the Small Supersonic Tunnels Section; from 1954 to 1958, he was Chief of the 8- by 6-foot Supersonic Wind Tunnel Branch at Lewis. In January 1958, he was appointed Chief of the Plasma Physics Branch.

A native of Hastings, Pa., Cortright served as an officer in the U.S. Navy from 1943 to 1946. He earned a bachelor of aeronautical engineering degree in 1947 and a master of science in aeronautical engineering degree in 1949, both from Rensselaer Polytechnic Institute.

During his research career, Cortright has specialized in high-speed aerodynamics, particularly problems related to air induction system design, jet nozzle design, and interactions of a jet with external air flow. He is the author of several technical reports and articles. He is a member of the Institute of the Aeronautical Sciences.

Cortright is married to the former Beverly Hotaling. Mr. and Mrs. Cortright and their two children, Susan J., 10, and David E., 8, live at 6909 Granby Street, Bethesda, Md.

HARRY WEXLER, DIRECTOR OF METEOROLOGICAL RESEARCH, WEATHER BUREAU, DEPARTMENT OF COMMERCE

Harry Wexler, Director of Meteorological Research at the U.S. Weather Bureau, has been Chief Scientist for the U.S. International Geophysical Year Antarctic program since 1955.

Dr. Wexler earned his undergraduate degree in mathematics from Harvard University in 1932. He was awarded a doctorate in meteorology by Massachusetts Institute of Technology in 1939.

He joined the Weather Bureau in 1934 at Chicago, and was named Chief of its Scientific Services Division in 1946. In 1955 he was appointed to his present position.

Dr. Wexler is the author of numerous technical papers, and a member of many professional societies. His awards include: Robert M. Losey Award for his outstanding contributions to the science of meteorology as applied to aeronautics by the Institute of the Aeronautical Sciences in 1945; the U.S. Air Force Award for his exceptional service as a member of the Scientific Advisory Board to the Chief of Staff, USAF, in 1956; and the Department of Commerce Exceptional Service Medal for his outstanding contributions to world meteorology during the 1957–58 IGY program, in February 1958.

In August 1955 Dr. Wexler was a member of the U.S. delegation to the Atoms for Peace Conference held in Geneva, Switzerland.

Dr. and Mrs. Wexler (the former Hannah Paipert) have two daughters. The Wexler home is located at 204 South Lee Street, Falls Church, Va.

BENJAMIN MILWITZKY, HEAD, GEODETIC AND NAVIGATIONAL SATELLITES PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Benjamin Milwitzky was appointed head of the geodetic and navigational satellites program in the Office of the Assistant Director for Advanced Technology in December 1958. Previously he was a scientist on the staff of the Dynamic Loads Division of the NASA's Langley Research Center, Langley Field, Va.

Born in New York City in 1921, Milwitzky earned a bachelor of science degree in aeronautical engineering from the University of Minnesota in 1943.

Following graduation, he joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, at the Langley facility as an aeronautical research scientist. He worked in the field of dynamics, specializing in research in hydrodynamic impact, structural dynamics, landing impact problems, and analyses of nonlinear systems.

Milwitzky is the author of numerous technical reports and articles for technical journals. He is a member of the Institute of the Aeronautical Sciences and the Scientific Research Society of America (RESA).

He lives at 114 Fifth Street NE., Washington, D.C.

LEONARD JAFFE, CHIEF, COMMUNICATIONS SATELLITE PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Leonard Jaffe was appointed chief of the communications satellite program in the Office of the Assistant Director for Advanced Technology, National Aeronautics and Space Administration, in January 1959. Previously he was Chief of the Data Systems Branch at the Lewis Research Center, Cleveland, Ohio.

Jaffe has specialized in research in the fields of electronic instrumentation, data and information transmission, and data processing by means of computers.

He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1949 as an aeronautical research scientist at the Lewis facility. During his 10 years in Cleveland, he was engaged in electronic instrumentation in the Physics Division; served as head of the Automatic Data Handling Section; and from 1956 to 1958, was Chief of the Data Systems Branch.

A native of Cleveland, Jaffe attended local grammar and high schools. He was graduated from Ohio State University in 1948 with a bachelor's degree in electrical engineering.

Jaffe is the author of several scientific publications and articles for technical journals. He is a member of the Institute of Radio Engineers.

Mr. and Mrs. Jaffe (the former Elaine Michael) have one son Ronald, 6. His family currently lives in Cleveland. They plan to move to the Washington, D.C., area within a few weeks.

Senator STENNIS. All right, sir, you may proceed in your own way.

Mr. CORTRIGHT. Mr. Chairman, members of the committee, there are a number of problem areas which are of interest and importance to us all which stand to benefit greatly, we think, by the application of earth satellites. These include meteorology, communications, navigation, and geodesy. At an earlier meeting this year I had the opportunity to talk to you briefly on these subjects and introduce them to you. Today, in the four talks which we would like to give, we will endeavor to explore these problem areas in more detail to improve your understanding of them and the manner in which the satellite will be applied.

Without further ado I would like to introduce Dr. Harry Wexler of the U.S. Weather Bureau. The Weather Bureau is cooperating in a program with NASA on meteorological satellites. Dr. Wexler will review the general problem area of meteorology and discuss the measurements which we might be able to make with satellites.

Senator STENNIS. Mr. Cortright, we remember your testimony from another hearing held in the other committee room. We are glad to have you back with us, and Dr. Wexler, we are glad to have you. I think this is something of interest.

TESTIMONY OF DR. HARRY WEXLER, DIRECTOR OF METEOROLOGICAL RESEARCH, WEATHER BUREAU, DEPARTMENT OF COMMERCE

Dr. WEXLER. I am to speak about the applicability of satellites to meteorology. There are no boundaries in the atmosphere, no state, national, or geographic boundaries. The air flows over the entire surface of the world and it is of such immense mass that if it were cut up and a piece of this given to each person on earth he would be responsible then for 2 million tons of air to watch. So that you can see that the job facing the meteorologist is a pretty large job when he has to predict the future development of something where at any given time he does not really know what is going on.

Well, the main reason for this is that we have never had an observing platform which is comparable to the global extent of the atmosphere. We have always taken observations at little spots here and there and tried to piece them together as I will illustrate in a few moments.

SATELLITES WOULD ENABLE GLOBAL WEATHER OBSERVATIONS

But now for the first time the meteorologists have an observing platform which is global in nature, and we expect that great things will come of this. I would like to start out by showing a preview of the sort of thing that meteorologists hope to get, a photograph which was actually obtained several years ago by an Aerobee rocket.

For many years while following the work of the rocket group, particularly at the Naval Research Laboratory, I urged them to try to take pictures from rockets of interesting weather situations.

But the rocket people said that they needed clear skies to track these rockets visually and they avoided interesting weather conditions or situations. Well, it so happened one day in early October of 1954 a hole appeared in a cloud over White Sands, N. Mex., and an Aerobee rocket was launched. Shortly thereafter clouds moved in and with them some rather showery weather.

I was in Rome at the time at an IGY meeting and when I came back one of the NRL scientists called me up and said, "What is this about a hurricane in Texas October 5." I told him there was no hurricane that I knew of. I checked to make sure. I said there would be showers and squally weather but no hurricane. He said, "It sure looks like some of these hurricane pictures that you people have been seeing on radar which resemble spiral nebulae."

I went over to the lab and looked at the picture. This is a composite picture taken by piecing together a hundred or so different pictures from an Aerobee rocket which was launched over White Sands to a height of 100 miles. The view here is looking to the southeast to the mouth of the Rio Grande River. This is east here. Way over here is southern Iowa. This is 2,800 miles long, this horizon. This is not the edge of the earth by any means, just the visible horizon, and over here is lower California.

The storm in question was this whirlpool-like cloud a few hundred miles in diameter which looked for all the world like spiral nebulae that astronomers see and which is sort of the fingerprint of a hurricane that we have learned to observe by radar. In going back to our weather maps we looked again and we couldn't see any hurricane on the surface and our conclusion was that this is a hurricane above the surface which did not introduce stronger winds than 35 miles an hour at the surface, but it did produce quite heavy rains. The same storm moved over New Mexico, produced flooding rains, and on up the Mississippi River Valley, hitting Chicago and again producing some more heavy flooding rains. So, for the first time really, meteorologists had seen a storm from above, not from below, where only a small piece of the sky could be seen. And this sharpened our interest in this matter and we started thinking about the applicability of satellites, way back in 1954.

APPLICABILITY OF WEATHER SATELLITES

Now to show how this picture might be applicable to today's weather, suppose in today's weather map, which I demonstrate here on the board, we don't have any observations at all, I mean none of the usual Weather Bureau observations. But suppose we had just a satellite flying above which had ability to take cloud pictures. Now this particular weather map would then show by means of cloud pictures a rather broad belt of cloudiness extending from the Hudson Bay southward over the Great Lakes, southwestward over Texas and Oklahoma. It would be rather clear off the Atlantic seaboard, southeast Florida, Gulf of Mexico, and rather clear in the Pacific Northwest.

Meteorologists looking at this area, this shaded area, would immediately interpret this in terms of two storms; a rather heavy concentration of clouds here on Hudson Bay which would be a storm which has passed the Great Lakes, a narrow belt of clouds coming down to the southwest, south of the Great Lakes which would be a cold front, which is approaching Washington at this very moment, and then another heavy concentration of clouds over the southwest area which is another storm taking place and which is expected to deposit rather heavy amounts of snow in Kansas, Missouri, and Iowa in the next 24 hours. Thus, meteorologists could again gain a good deal of information just from cloud pictures which satellites could make available.

Of course over the United States we have a lot of weather reports obtained by weather stations of this type. This happens to be a polar weather station in the Arctic Basin where we have an instrument shelter. A man reads the temperature, barometer, and pressure and so on. He releases balloons which carry instruments and observe temperature pressure and humidity as they go up and radio down information. This is done in qute a number of other stations and the information is put together and forecasts are made for different purposes as shown here on this chart.

The same data are released for climatology purposes and also for research purposes. These observations involving the upper air balloon, the radiosonde, are made at perhaps 400 spots throughout the world as shown here on this map of the world. And you can see that the distribution of these observing spots is very uneven. They are mostly around centers of population; the United States, Canada, Western Europe, Asia, central Europe, and even part of the Asiatic Continent.

The Southern Hemisphere is quite deficient and the reason for that, of course, is that it is mostly ocean and it is very expensive to maintain such stations in the ocean. The ships that are used in the North Atlantic air routes and Pacific air routes are very expensive to maintain. Consequently we have gaps in the oceanic areas, not only in the Southern Hemisphere but in the Northern Hemisphere. You could fit the United States in these gaps several times, and storms may reside there for several days without people becoming aware of them. A particularly important gap to the southeast in the Atlantic coastal area of the United States, this big gap over here, where during the summer season hurricanes can breed and then move in and approach the west coast of Florida and the Gulf of Mexico for some days without anyone being aware of it. Once we are aware of them, of course, we go and send airplanes into these storms to get detailed observations.

So a satellite flying over these areas and looking at clouds can give information to meteorologists which would enable them to say well, there is a very suspicious area over here. Clouds are taking a shape that is beginning to look like a pinwheel sort of distribution. Let's send our airplanes in there and make sure whether there is something brewing. Even over the Pacific here there are many blank areas from which storms day by day come in to affect the United States. Most of

our weather moves from west to east. Here again satellites could raise an alarm toward suspicious areas. Of course, this would apply for the whole world, and in the tropics and in the Southern Hemisphere where observations are particularly deficient, the satellite promises probably to be the biggest means of improving weather forecasts that have been developed for generations.

METEOROLOGICAL SATELLITE CAPABILITIES

Now the sort of complete meteorological satellite that one would like to see flying around in some number would be a satellite that would have various types of instruments to measure various phenomena depicted around the edge of this picture. The first aim, of course, would be to get cloud pictures as I mentioned. Instead of using photocells, which is the technique used for obtaining pictures from the satellite launched February 17th, which went out of commission March 7th due to exhaustion of the power supply, we would use a television camera which would give us a snapshot of the distribution of clouds such as shown here. This is an artist's concept of a picture taken by a satellite say 4,000 miles above Texas and observing a hypothetical situation of storms. The pattern, incidentally, for some coincidence or other, appears to be quite similar to the one on today's map which I showed a moment ago with a rather major storm over the Great Lakes and southern Hudson Bay area coming down to a front and another developing storm in the Southwest States.

A hurricane would show up here as a small pinwheel which you can hardly see from where you are sitting. There would be other observations made on this meteorological satellite. There would be observations of the incoming solar radiation, the reflected solar radiation from the clouds and the atmosphere and the Earth's oceans and snow fields, and then the direct radiation from the Earth and the atmosphere.

MEASUREMENT OF SOLAR RADIATION PLANNED

If we only received solar radiation and did not get rid of it we would warm up so that it would become much too warm. We arrive at some equilibrium temperature whereby we send back just about as much energy as we receive from the Sun. So an instrument that will be flown on a meterological satellite some time in this year will be one to measure these radiation streams, which is extremely important, because the atmosphere moves, one might say, because of the unequal distribution of solar heating. Equatorial regions receive more solar energy than they need. The polar regions receive less. The atmosphere ceaselessly attempts to equalize this unequal heating and in so doing creates winds, weather and storms.

But in addition to that fuel which energizes weather, it is very important for people to know whether over the long period of time, a few years, the Earth as a whole is receiving more energy from the Sun than it is giving back to space. If it is, then it is warming up as a whole. The textbooks say that they are equal but no one really knows because we have never had an opportunity to measure the radiation

budget of the Earth as a whole, but now with satellites flying with the proper equipment and in an uninterrupted manner we should be able to see whether there is a net radiation gain or loss which has very great meaning for our future climate.

As you know, the atmosphere has been warming up over large portions of the world's surface for many years. We don't know whether this is true for the world as a whole but the regions that have warmed up a lot are especially found in polar regions.

In Spitzbergen, for example, the average annual temperature in the last 50 years has warmed up by 11 degrees Fahrenheit and at Little America and the Arctic the average temperature has warmed up by 5° F. If this trend should continue there is enough potential ice locked up in the polar regions which would melt to raise the sea level by 200 feet. This has happened once before when our last ice sheets vanished in North America 10,000 years ago. The sea level went up by 220 feet, so there is a similar potential waiting the future generations of the world. Certainly, that can't happen very fast. It would take hundreds and thousands of years for this to take place even under the most favorable, or unfavorable, circumstances.

WORLD RECORD OF PRECIPITATION COULD BE OBTAINED

Now other things that would be measured in the future, not in the immediately launched satellites, would be the heights and the thickness of cloud layers and the precipitation that is falling over the world, so one could get a world record of precipitation, by means of radar.

Thunder storms would be observed by the creation of static, or as meteorologists call it by determination of spherics. Other things that could be measured by means of infrared radiation would be temperatures in the stratosphere, the tropopause, cloud tops, and the surface. Perhaps constituents could also be measured, such as the amount of water vapor to be found in the vertical column, ozone, which is extremely important, and carbon dioxide, which is also a very important gas and which may be increasing rather significantly as we burn out fossil fuels.

So this represents the sort of observations that meteorologists would expect to obtain in a routine manner some years from now as a complete meteorological system is placed into operation.

SYSTEM OF VARIOUS TIME AND ORBIT SATELLITES ANTICIPATED

I envisage a system of perhaps five or six satellites going on polar orbits or quasi-polar orbits so that they will retain their orientation with respect to the Sun. One might be a noon satellite, one might be a 4 p.m. satellite, one might be an 8 p.m. satellite and so on.

And then also another satellite which would be going around the equator from west to east for use particularly in the detection of hurricanes and other tropical weather phenomena. All these data would feed into central weather compository, forecasts would be prepared therefrom and the information would be made available to all by means of the World Meteorological Organization which is an organization composed of 97 nations.

I do not wish to leave the impression that use of satellites will solve every problem in meteorology, nor will it mean the elimination of all of our present networks. We will still need very detailed observations useful for agricultural purposes, aviation purposes, and severe storms. This will still be needed. The satellites could not hope in my opinion to give the very fine structure detail that we now obtain from our other means. But the satellite will give as background information the world weather picture. It will keep track of each and every significant storm so that meteorologists will know when these storms are about to strike. By storm I mean a rather big area of several hundred miles across.

It may with finer equipment narrow some of these things down to a better determination of squall lines and severe thunderstorms and even tornados, but these things are so transitory and so small that it would appear as if a fine surface network and airplanes and radiosondes would still be required.

The satellite would help us keep track of global climate, find out whether the climate is warming or cooling for the earth as a whole, determine the amount of solar radiation that goes into energizing storms, and, last but not least, it may give us such improved understanding of the atmosphere and its ways that it may throw open the way for some form of large-scale weather modification.

Thank you, Mr. Chairman.

METEOROLOGICAL CONSIDERATIONS

METEOROLOGY

DEFINITION

THE SCIENCE OF THE ATMOSPHERE AND IT'S PHENOMENA, ESPECIALLY AS RELATED TO CIRCULATION AND WEATHER

GOALS

IMPROVED SCIENTIFIC UNDERSTANDING
IMPROVED FORECASTING
WEATHER CONTROL

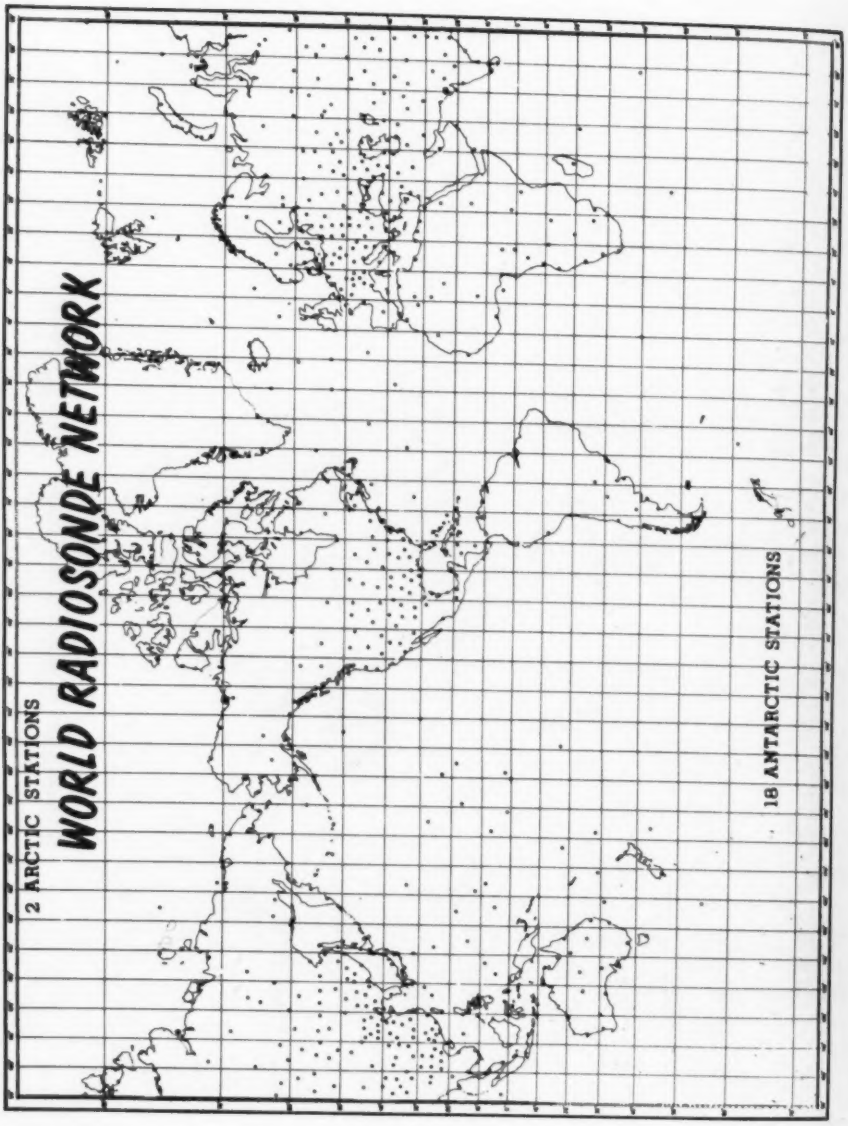
MEASUREMENTS AND TECHNIQUES

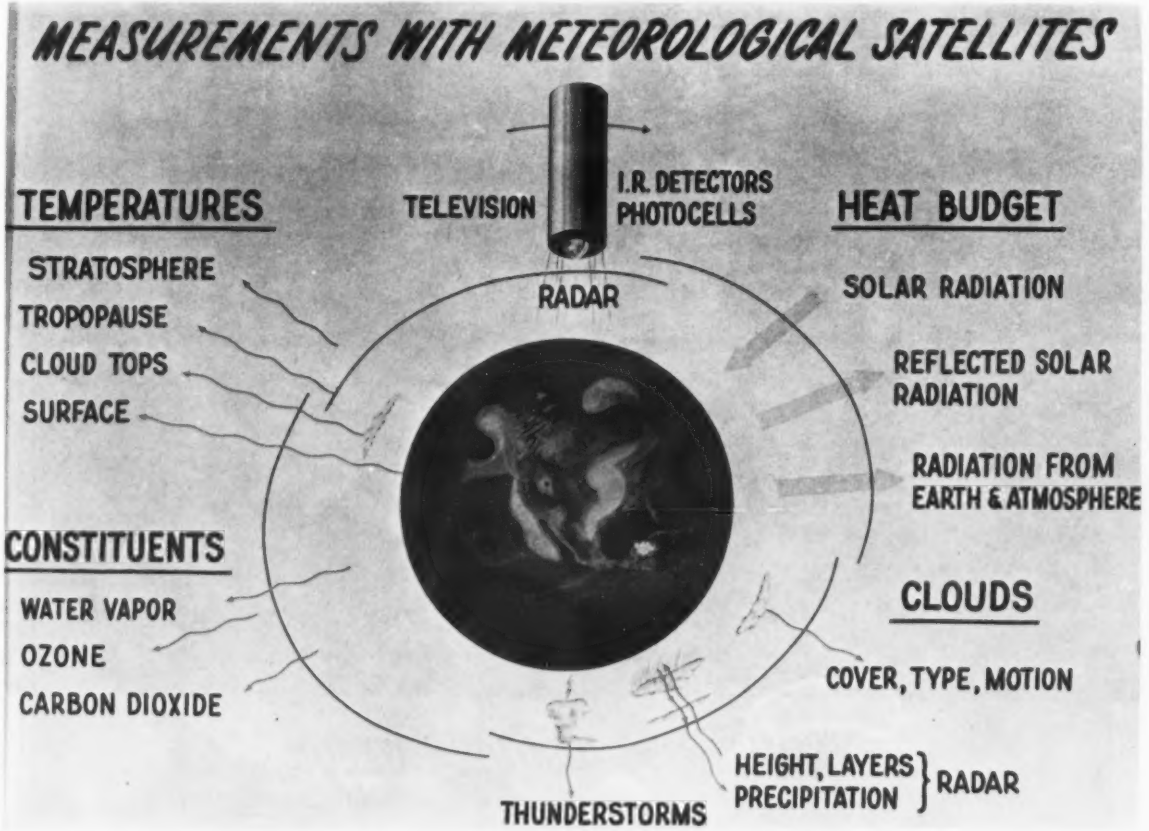
FORECASTING (SUBJECTIVE & OBJECTIVE)
- SHORT-RANGE (OUT TO 48 HR.)
  - GENERAL STATE & CITY FORECASTS
  - AIRWAYS FORECASTS (DOMESTIC AND FOREIGN)
  - SEVERE LOCAL STORM FORECASTS
  - FORECASTS FOR SHIPPING
  - FRUIT-FROST FORECASTS
- EXTENDED-RANGE (2-6 DAYS)
- LONG-RANGE (30 DAYS)

CLIMATOLOGY

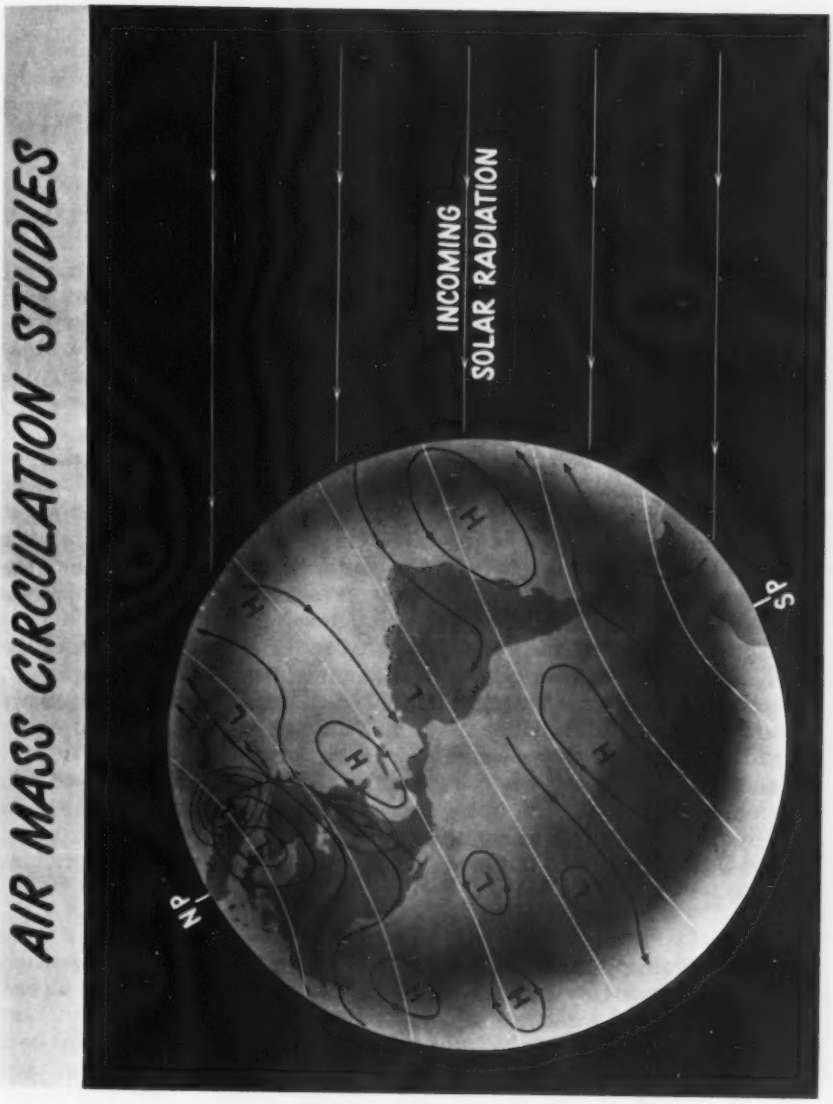
RESEARCH
- ATMOSPHERIC STRUCTURE
- ATMOSPHERIC COMPOSITION
- GENERAL CIRCULATION
- HURRICANES
- TORNADOES
- NUMERICAL WEATHER PREDICTION
- LOCAL FORECAST STUDIES

MEASUREMENTS
- TEMPERATURE
- PRESSURE
- HUMIDITY
- WIND
- PRECIPITATION
- CLOUDS


WORLD RADIOSONDE NETWORK
2 ARCTIC STATIONS
18 ANTARCTIC STATIONS


MEASUREMENTS WITH METEOROLOGICAL SATELLITES
TEMPERATURES
STRATOSPHERE
TROPOPAUSE
CLOUD TOPS
SURFACE
CONSTITUENTS
WATER VAPOR
OZONE
CARBON DIOXIDE
TELEVISION
I.R. DETECTORS
PHOTOCELLS
RADAR
HEAT BUDGET
SOLAR RADIATION
REFLECTED SOLAR RADIATION
RADIATION FROM EARTH & ATMOSPHERE
CLOUDS
COVER, TYPE, MOTION
HEIGHT, LAYERS
PRECIPITATION
RADAR
THUNDERSTORMS

CLOUD COVER AND STORM DETECTION


AIR MASS CIRCULATION STUDIES
INCOMING
SOLAR RADIATION
NP
SP
H
L

Senator STENNIS. Thank you very much, Dr. Wexler. We may have some questions for you later. We will follow our previous course. All right, Mr. Cortright, we are back to you.

Mr. CORTRIGHT. I would like to continue now with some discussion of the systems which we envision might be put together to make use of these meteorological satellites.

Senator STENNIS. All right, proceed.

TESTIMONY OF EDGAR M. CORTRIGHT, CHIEF, ADVANCED TECHNOLOGY PROGRAM, NASA

Mr. CORTRIGHT. The system shown in the first chart here is very similar to the one Dr. Wexler just described. I will review it very briefly because you have seen this at an earlier presentation.

The low altitude satellites traveling in polar orbits are indicated here. These satellites would be from 500 to 800 miles high, we think, which is a proper altitude to permit the area observed beneath the satellite to have the desired width without requiring excessively wide-angle lenses in our cameras. This type of satellite at this altitude would be best suited for the high definition measurements indicated on this other chart by Dr. Wexler. We also envision that we would need satellites in 24-hour orbits—in other words, 22,300 miles above the Equator, and I have shown four of them here. This type of satellite would sit overhead of some position on the Earth, and, at the direction of a meteorologist observing the weather at a weather central, the television viewing area could be moved throughout the hemisphere under observation in order to search for significant areas and to observe weather situations as they develop.

I might point out that the problem of getting these data from the satellites back to weather central is a tremendously difficult one. The information from one satellite alone that is not in the immediate vicinity of Suitland Weather Center, say, would be sufficient to swamp the world's communication network as it now exists.

Hence it is necessary when one envisions a system like this to also envision a system of communications satellites to provide the data tranfer. This problem of communications satellites will be discusssed by Mr. Jaffe in just a moment, so I will say no more about it at this time.

METEOROLOGICAL SATELLITE PROGRESS

Now this is an ambitious system. We think that this is approximately the type of system that will be required. It may be we can get by with fewer satellites when the time comes. We simply don't know. We are taking only step number one, and it is going to be a long and difficult process to arrive at something as advanced as this.

In the course of developing this system, however, we will arrive at certain milestones which I would like to point out to you.

For example, the first milestone, I think, was the meteorological satellite which Dr. Wexler referred to and which I had an opportunity to describe to you a month or so ago. This is the cloud cover satellite which was launched. It was developed by the U.S. Army Research and Development Laboratory as an IGY experiment.

This satellite incidentally typifies the sort of frustrations we go through in this business. Although it did operate perfectly electronically, it was injected into orbit with sufficient wobble so that it is turning out to be an exceedingly difficult job to make pictures from the electronic signals.

The second milestone I would like to refer to is an advanced meteorological satellite which was developed primarily by the Department of Defense with the NASA cooperating. It is now being transferred to the jurisdiction of the NASA. This satellite, which will be launched toward the end of this year, will include television and various other radiation detection instrumentation.

Later on, perhaps in 1960 hopefully, we would be able to launch our first polar orbit, which is a much more desirable orbit from a meterorologist's point of view.

Our next milestone might be our first experiment with the 22,300-mile equatorial orbit. Shortly after that we think we can have satellite-borne radar and attempt our first measurements at determining precipitation and storms by radar techniques.

Then another milestone which you might not normally think of is the establishment of the first real time data link for large amounts of data. I don't mean to imply that we will not have real time data in these early experiments. By "real time," I mean we get the data back at the Weather Bureau almost as soon as it is taken. The only way we can get data back now is to put human intelligence at the ground site, interpret the pictures and send back a condensation of all the data, such as, "a storm over Cyprus or a storm over the Caribbean." But to get the pictures back we will require the advanced system and this, I think, will be a very important milestone.

At the moment we achieve this, we should have the satellites already developed to make use of it. And then, of course, when the fully operational system is finally achieved, this will be the final milestone. I am not attempting to put any time scale on this other than the fact that we believe it is possible to develop such a system within a decade.

PRESENT STATUS OF METEOROLOGICAL SATELLITE SCHEDULE

Now where are we today? Milestone number one has come and gone, and I described this chart to you once before. I won't belabor it at this time. It was a spherical satellite with photocells looking out in diametrically opposite directions. The photocells generated a signal to modulate a carrier and the strength of this signal was a function of just how bright was the spot that the photocell was viewing. By demodulating this signal you can reconstruct a picture on the ground. You might be interested in why it is so difficult to do it now that the satellite is wobbling.

The difficulty lies in the fact that successive scans are not parallel, as they were intended, but crisscross. It becomes, as you can imagine, an extremely difficult problem mathematically to plot the points in their proper location, even once you have determined the mechanics of the orbit. We have not yet established precisely what the wobble is. If the wobble changes during the course of the flight, that will just present added complications.

Now the next meteorological satellite which will be launched before midsummer is shown on this chart. This is a satellite to determine heat balance measurements of the type that Dr. Wexler described. It is a rather ingenious satellite, I think.

It is four spheres at the ends of the telemetering antennas. One is a black sphere which will absorb radiation in all wavelengths. Another is a white sphere which absorbs the long wavelengths. Then there are two coated spheres to absorb the short wavelength radiation. One is shielded by an open-ended cylinder in such a way that during a portion of the orbit it receives only radiations from the Earth. Another is shielded by the "missing" two ends of the cylinder so that at that same period it would see only radiation from the Sun.

Now when you take these four measurements of temperatures within the spheres and put them together in the proper electronic circuity, the signal which comes back is a measure of the heat balance.

I have with me, in the event that there is time and interest, two charts to illustrate the more advanced satellite, which I referred to on an earlier chart, with the television cameras and the various radiation detectors. However, this project is classified at the moment and I will leave it up to the judgment of you gentlemen whether you would like to see them later.

I would like then to close with another indication of the utility of this type of observation. This is a simulated photograph showing approximately 400 miles by 500 miles as seen from a hypothetical satellite in the neighborhood of 400 miles altitude. This, of course, was not taken from the satellite. Actually these film strips were obtained by two naval photo reconnaissance aircraft flying in parallel over Florida. It was done at the request of ARPA in connection with the advanced meteorological satellite experiment.

Now the satellite which will be put up later this year would see four times this area in a single picture with its television camera, and instead of seeing strips of clouds, it would see clouds over that whole area. What I want to point out here is these heavy white bands of clouds, which probably extend something like this and indicate a cold front.

Dr. Wexler indicated before that we would probably be able to determine cold fronts by cloud photographs. Well, this is another positive indication that this will be the case. And that concludes, gentlemen, what we wanted to discuss today on meteorological satellites.

METEOROLOGICAL SATELLITES

METEOROLOGICAL SATELLITES

PURPOSE:

- TO IMPROVE OUR SCIENTIFIC UNDERSTANDING OF THE WEATHER AND OUR ABILITY TO MONITOR AND PREDICT IT FOR THE BENEFIT OF ALL.
  - SOCIAL CONVENIENCE
  - PERSONAL SAFETY
  - PROPERTY SAFEGUARDS
  - ECONOMIC PLANNING – INCLUDING AGRICULTURE
  - MILITARY STRATEGY AND TACTICS

MEASUREMENTS:

- CLOUD COVER – TYPES, LAYERS, THICKNESS, HEIGHTS WIND DIRECTION
- DISTRIBUTION OF WATER VAPOR, CARBON DIOXIDE & OZONE
- TEMPERATURES
- RADIATION BALANCE (ATMOSPHERIC HEAT PUMP INPUT)
- SPECTRA OF SOLAR, ATMOSPHERIC AND TERRESTRIAL RADIATION
- ELECTRICAL DISTURBANCES

KNOWN USEFUL INSTRUMENTS:

- TELEVISION, RADAR, INFRA RED, BOLOMETERS, DETECTORS

INSTRUMENTS.

METEOROLOGICAL SATELLITE MILESTONES

1 FIRST METEOROLOGICAL SATELLITE - 1959 IGY EXPERIMENT
CLOUD COVER WITH PHOTOCELLS

2 ADVANCED METEOROLOGICAL SATELLITE - 1959 DOD-NASA
TV AND I.R. CLOUD COVER
OTHER I.R. MEASUREMENTS

3 FIRST POLAR ORBIT - 1960

4 FIRST 22,000 MILE ORBIT

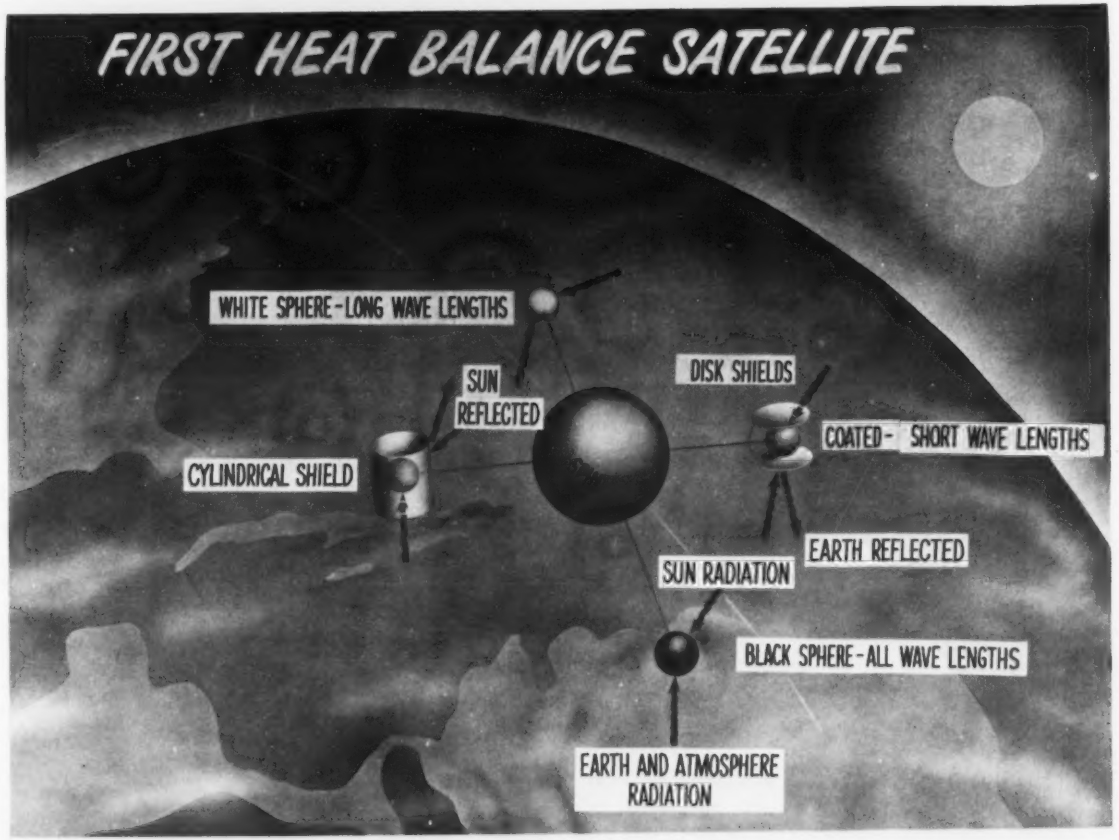
5 FIRST USE OF RADAR

6 ESTABLISHMENT OF "REAL TIME" WORLDWIDE DATA LINK,
POSSIBLY VIA COMMUNICATION SATELLITES

7 FIRST FULLY OPERATIONAL SATELLITE WITH "REAL TIME"
DATA INPUT TO WEATHER CENTRAL

8 FULLY OPERATING SYSTEM AS DEPICTED

VER SATELLITE
SPIN
PICTURE RECONSTRUCTION


FIRST HEAT BALANCE SATELLITE
WHITE SPHERE-LONG WAVE LENGTHS
SUN REFLECTED
CYLINDRICAL SHIELD
DISK SHIELDS
COATED- SHORT WAVE LENGTHS
EARTH REFLECTED
SUN RADIATION
BLACK SPHERE-ALL WAVE LENGTHS
EARTH AND ATMOSPHERE RADIATION

HIGH ALTITUDE CLOUD PHOTOGRAPH
7 NOV. 1958
1238 E
1118 E
SCALE

Senator STENNIS. That is very good and very interesting. We think you have made a splendid contribution there.

Mr. CORTRIGHT. Thank you, sir.

Senator STENNIS. Who is the next witness?

Mr. CORTRIGHT. Mr. Leonard Jaffe will describe for you the area of communications satellites.

Senator STENNIS. All right, Mr. Jaffe, we are very glad to have you, sir.

TESTIMONY OF LEONARD JAFFE, CHIEF, COMMUNICATIONS SATELLITE PROGRAM, NASA

Mr. JAFFE. Mr. Chairman, and gentlemen, there have been a great many studies made recently to indicate the need for much more advanced global communications than exist today.

The need for military communications, rapid military communications is quite obvious. The need for a much greater facility for commercial communications is not quite so obvious. Let's just take a look at the current telephone message trends.

This chart depicts some trends in overseas telephone messages.

We see here that in 1950 approximately 1½ million overseas telephone calls were made. In 1960, 3 million telephone calls will have been made, and it has been predicted by several agencies that in 1970 a total of 21 million messages will be made. Several independent analyses have indicated this sevenfold increase in commercial communications demands over the next decade. These demands are predicated largely on present economic conditions remaining the same, that no new vast areas of commercial interest will develop. They further do not include the type of thing that Mr. Cortright talked about, the need for vast communications systems for handling data, nor do they include the need for global television communications which require many times the capabilities of ordinary telephone lines that we are talking about here.

The present Trans-Atlantic telephone cable which was installed in 1956, will have its capacity exceeded in 1962. There is under development an advanced transistorized cable with approximately twice the capacity that might become available within the next decade, but its capacity would be exceeded in 1965. Satellites or communications via satellites seem to present one of the most interesting solutions to this problem.

There are several techniques for using satellites to promote communications, and these techniques differ markedly in the amounts and complexity of the equipment carried aboard the satellite and the extent and complexity of equipment necessary on the ground.

PASSIVE COMMUNICATION SATELLITES

One of these systems is called the passive communications satellite, and this refers to a satellite in which there are no electronics. This system is shown on the next chart. With this type of satellite communications is established by merely reflecting radio waves which impinge upon the satellite back toward the earth. We can see here that all of the power which is necessary to accomplish communications

between two stations must originate on the earth, since there is no power available in the satellite itself.

Therefore, we require large or high powered transmitters at the ground sending station. We require large antennas to beam the energy toward the satellite. And since this reflected energy from the satellite is spread out in all directions, the receiving station must necessarily be a very sensitive receiving station requiring very low noise amplifiers or very highly sensitive receivers. Further since the satellite is moving in its orbit, we need large steerable directional antennas to concentrate as much energy at the satellite and to absorb or pick up as much of the reflected energy as possible.

In addition to this it would require computing equipment to calculate the trajectories and provide this antenna pointing information as the satellite progressed in its path.

The NASA has under development at its Langley Research Center an inflatable structure, an inflatable sphere which might be used as a communications satellite. A picture of this sphere is shown on the next chart. This sphere is an aluminized mylar plastic sphere approximately 100 feet in diameter. It is composed of material which is approximately a quarter of a mil, or a quarter of a thousandth of an inch, thick.

It weighs approximately 65 pounds. This sphere would be packaged in a small container prior to launching. Prior to launching the material is folded into a spherical container approximately 30 inches in diameter, and a small amount of water is injected inside the sphere. After the container has been injected into orbit at altitude, this container would be broken open and since we are now in a vacuum in space, the water inside of the mylar sphere would begin to boil. The steam generated would then expand the sphere to its full 100-foot diameter in orbit.

The present plans call for an experiment of this type to be carried on by NASA in the late fall of this year. It is intended that a 100-foot sphere be launched into an orbit at about a thousand miles altitude at an inclination of about 50 degrees to the Equator.

Now what does one sphere do for us? I have shown here on this map the area of influence of one sphere shown in red. This red sphere would be seen essentially from any point within this red circle. So that two stations within this area of influence could communicate with each other. This antenna, for instance, could transmit, bounce a signal off this red balloon and the signal would be received by this other antenna. Now since these spheres are moving in their orbits, it is quite obvious that as it moves this area of influence or area of reception would move along with it, and one of these antennas would then be outside the area.

Senator STENNIS. If you will permit an interruption, point out where your red line is there on the map of the world when you say it would transmit a message to the red ball. Geographically where are you?

Mr. JAFFE. This could be any place.

Senator STENNIS. I know, but where is it now?

Mr. JAFFE. Oh, in this particular point? Well, let me say that the radius of this circle is approximately 4,000 miles.

Senator STENNIS. Yes.

Mr. JAFFE. In this particular case we have chosen the ultimate altitude we would like to get which would be about 3,000 miles so that we cover an area with a radius of 4,000 miles. This would take us for this particular red circle from the Soloman Islands to the west coast of the United States.

Senator STENNIS. That is what I wanted in the record. Proceed.

Mr. JAFFE. As this satellite, the red satellite we are looking at, moves out of the range of these two particular stations that we are interested in, we could provide another to move into its place, thus we see that the single satellite does not give us general coverage, but a multiplicity of satellites of this type could give us general global coverage. In the present vehicles, vehicles we have available to us today, we have the capability of launching one satellite at a time, but future vehicles might make it possible to put a multiplicity of these satellites into orbit with a single rocket.

Now, the communications experiment that we are going to perform this fall will involve two stations, one here in California at Goldstone, California, and another in New Jersey, spanning the continent.

We will establish communications at one frequency going from east to west, and at another frequency from west to east; doing this at two different frequencies allows us to obtain some very interesting propagation data in addition to proving the feasibility of this type of system. In addition to this more or less in-house experiment that we are performing, we will encourage private enterprise to make their own observations using this balloon. Indeed, there is nothing within the balloon to prevent anyone from reflecting radio signals from it and from obtaining their own data.

ACTIVE REPEATER SATELLITE

I mentioned the difference between the different communication satellite systems was the extent or complexity of the equipment carried within the satellite.

Here we have an active repeater satellite. As opposed to the passive repeater satellite, this satellite does contain electronics. It contains a receiver, a transmitter, an antenna, and of course the associate power supply to power this unit. A signal transmitted from the ground would be received by the satellite and immediately retransmitted on another frequency to a remote ground station. Since we have power available to us in the satellite we could use receivers of rather standard characteristics. We wouldn't have to go to the very low noise and very sensitive receivers that are required for the passive communications satellite. We could use transmitters of nominal power, because we are essentially going only half as far in each case. In the case of a low orbit satellite we would still have to follow the satellite with our steerable and directional antennas.

Senator STENNIS. Excuse me just a moment. Off the record.

(Discussion off the record.)

Mr. JAFFE. We talk here about a low-altitude orbit. There does exist a so-called 24-hour orbit that Mr. Cortright mentioned, at 22,300 miles altitude from the Earth, at which the satellite remains fixed with respect to a point on the Earth's surface. If we were to take three active satellites and deploy them as shown here in this 24-hour

orbit, we could get complete coverage of the Earth's surface with perhaps the exception of the polar regions. A signal could be sent from one side of the Earth to the other side of the Earth in perhaps two bounces, as shown here. The signal might originate here, transmit it to the satellite, come back to an intermediate point, be retransmitted to a second satellite, and finally to its destination on the other side of the Earth. An alternate technique that might be used is a satellite-to-satellite transmission, in which case the signal would go from its originating point to the first satellite, from satellite to satellite, and then to its destination.

Systems of this type probably represent an ultimate communications capability. However, it also represents a significant technological advance over present-day technology. It requires weights in the order of 800 to 3,000 pounds, depending on the complexity of the satellite. It requires solar cells or a reactor type of power supply, and in addition to this extremely reliable electronic equipment to give us a minimum of 2 to 3 year's useful life. It also requires the ability to stabilize the satellite and to point the antennas continuously toward the center of the Earth. These are all areas of technology which must be developed.

Senator STENNIS. Would you put a timetable on that? It must be developed; would you go any further than that?

Mr. JAFFE. I would say we will see satellites of this type, perhaps not a complete system, but satellites of this nature within 5 or 6 years.

RESEARCH AND DEVELOPMENT AREAS

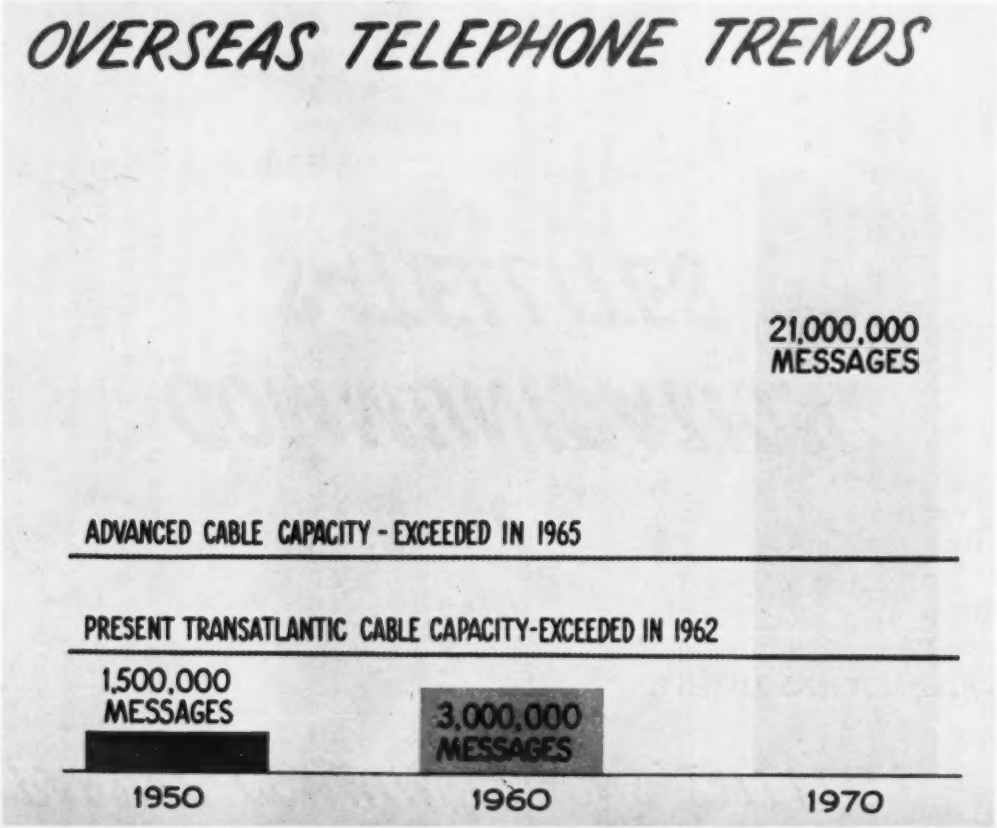
To recapitulate, and to emphasize the development areas which need to be pursued, in the case of the passive satellite we need the low-noise amplifiers, the very sensitive receivers. We need very high powered ground transmitters. Low-noise directional antennas, and fast tracking antenna mounts to continuously point the antennas at the satellites, and systems which will calculate where the satellite is and point the antennas at the satellite.

In the case of the active 24-hour satellite, we do not have the vehicles today to carry the required weight to the altitude. However, these vehicles are under development.

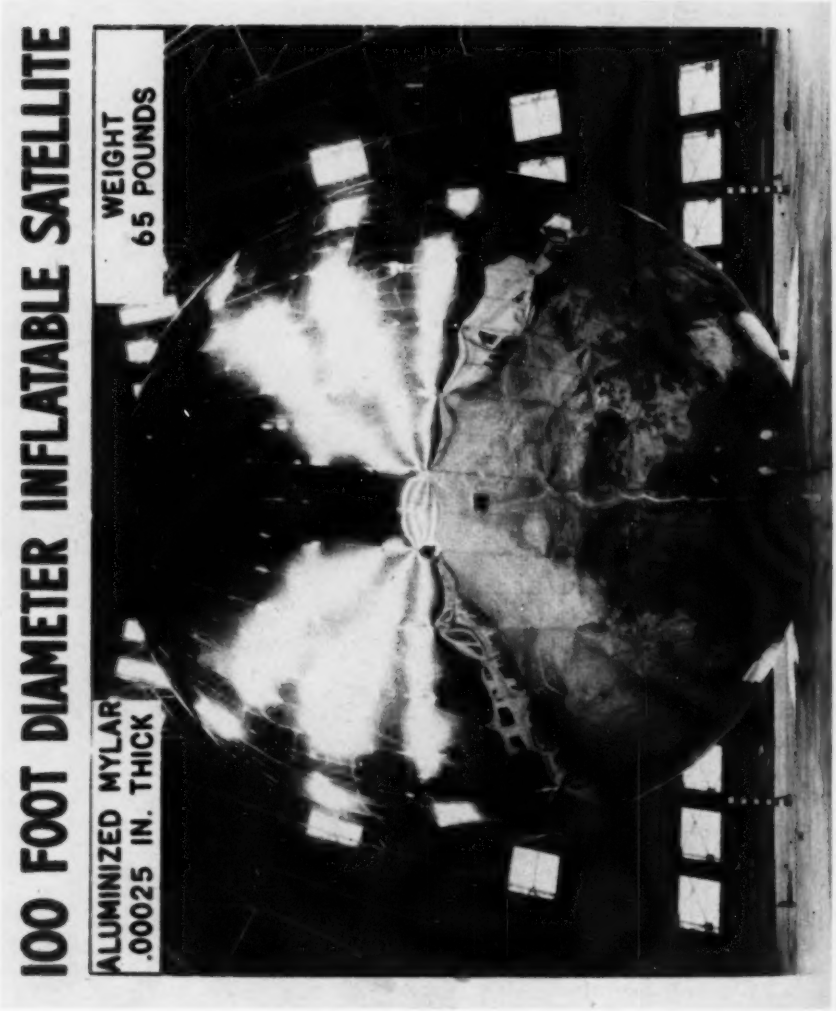
We need orbital correction systems to insure that that satellite stays put at its assigned position with respect to the Earth. These will generally drift with time, and the orbit must be corrected periodically. We need attitude-stabilization systems and antenna-pointing systems to point the antenna toward the Earth. We need extremely reliable electronics. There is no way of correcting mistakes or repairing failures. We need solar or reactor-type power supplies of long life.

I would like to conclude by saying that, the NASA, in addition to establishing the feasibility of such systems, wants to provide the technology from which the engineering designs for such systems can be made. In addition to this, as Mr. Cortright mentioned, the NASA will have its own need for such communications systems for its vast data-handling problems such as the meteorological stellite which has been described.

COMMUNICATION SATELLITES


OVERSEAS TELEPHONE TRENDS
21,000,000
MESSAGES
ADVANCED CABLE CAPACITY - EXCEEDED IN 1965
PRESENT TRANSATLANTIC CABLE CAPACITY-EXCEEDED IN 1962
1,500,000
MESSAGES
3,000,000
MESSAGES
1950
1960
1970

1950 1960 1970


100 FOOT DIAMETER INFLATABLE SATELLITE
ALUMINIZED MYLAR
.00025 IN. THICK
WEIGHT
65 POUNDS

100 FOOT
SPHERE
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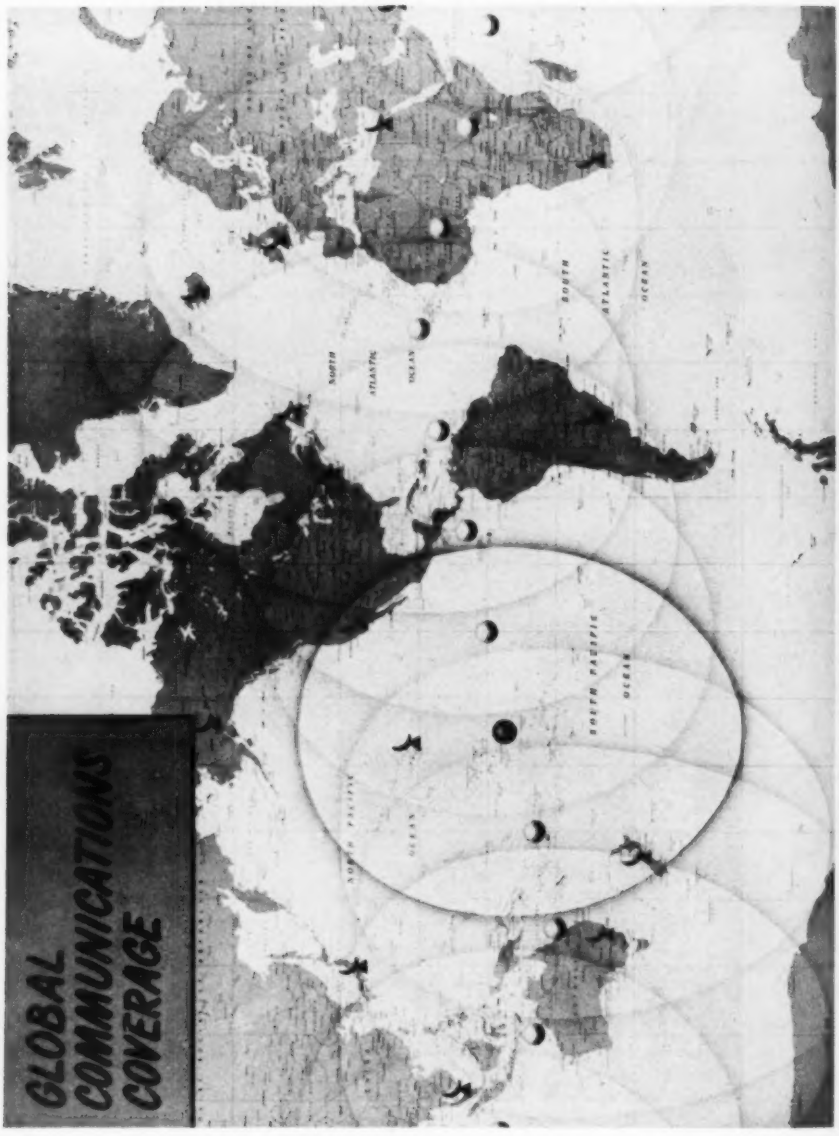
PACKAGE
30" DIA.

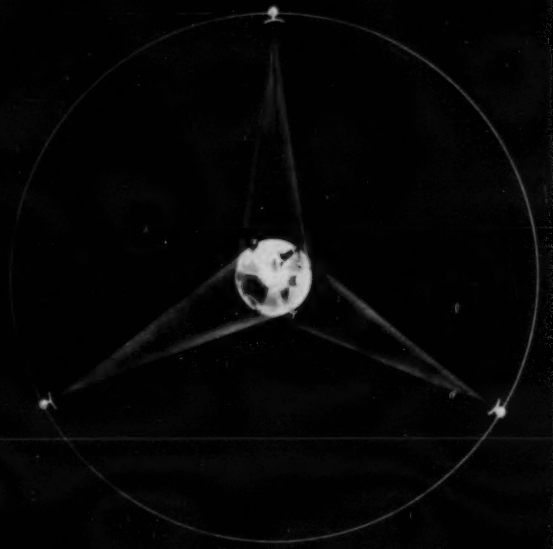

GLOBAL
COMMUNICATIONS
COVERAGE

ACTIVE REPEATER SATELLITE

ACTIVE REPEATER-24 HOUR ORBIT

SATELLITE CHARACTERISTICS

WEIGHT	800 TO 3,000 LBS.
POWER SUPPLY	SOLAR CELLS OR REACTOR
LIFE	2-3 YEARS
ORBIT	22,300 MILE ALTITUDE EQUATORIAL
ANTENNAS	DIRECTIONAL, ATTITUDE STABILIZED



SATELLITE COMMUNICATIONS DEVELOPEMENT AREAS

PASSIVE SATELLITE

LOW-NOISE AMPLIFIERS

HIGH POWER GROUND TRANSMITTERS

LOW-NOISE DIRECTIONAL ANTENNAS

FAST TRACKING ANTENNA MOUNTS

ANTENNA POINTING SYSTEMS

ACTIVE 24 HOUR SATELLITE

VEHICLES

ORBIT CORRECTION SYSTEMS

ATTITUDE STABILIZATION SYSTEMS

ANTENNA POINTING SYSTEMS

RELIABLE SATELLITE ELECTRONICS

SOLAR OR REACTOR TYPE POWER SUPPLIES

Senator STENNIS. While you have that graph up again, I think you can fill out the record about your passive satellite—put your passive satellite graph up. Tell us how many satellites would be required when you refer there to worldwide coverage.

12–24 SATELLITES REQUIRED FOR WORLDWIDE COVERAGE

Mr. JAFFE. Well, in this particular case, if we could space the satellites uniformly around the surface of the Earth, it would require only 12 satellites. If we were to assume that these satellites did not remain uniformly spaced but were allowed to drift randomly with respect to each other, it would take approximately twice as many. The number that would actually be required depends then on our ability to hold uniform spacing between satellites.

Senator STENNIS. How long would you expect one to serve, the lifespan?

Mr. JAFFE. This is one of the objects of the early experiments. We know very little today about the atmospheric drag, about the atmospheric density at these altitudes. Because it has such a large surface area, the life of the satellite is very seriously affected by the amount of atmosphere still left at that alitude.

Senator MARTIN. What is that altitude?

Mr. JAFFE. The initial experiment would be carried on at a thousand miles, and in the ultimate system we would like to see these satellites at altitudes of 3,000 to 4,000 miles.

ALL SATELLITES COULD BE LAUNCHED FROM SAME LOCATION

Senator STENNIS. Mr. Lehrer has a question here. Could we launch all these passive satellites from one place?

Mr. JAFFE. Yes.

Senator STENNIS. To get uniform spacing?

Mr. JAFFE. There have been proposals advanced which would indicate that this is possible; these are being evaluated today.

Senator STENNIS. Otherwise there would have to be a strictly international proposition, would it not?

Mr. JAFFE. They definitely could be launched from one place. It is a question of the uniform spacing, whether or not this can be accomplished.

Senator STENNIS. Yes. All right, gentlemen, it seems like we might just as well proceed. Did you have some questions particularly on this, Senator Cannon? Senator Martin?

NASA HAS PRIMARY RESPONSIBILITY FOR PROGRAM

Senator MARTIN. I would like to ask do you have this program alone in NASA, or are you working with other organizations?

Mr. JAFFE. The passive communications satellite program is alone in the NASA. ARPA does have an active communications program, and we are currently attempting to cooperate on this program.

Senator MARTIN. When you estimated the number of years ahead to perfect this, you had in mind NASA taking the primary responsibility for that, did you?

Mr. JAFFE. The number of years that I advanced is primarily predicated upon the testing period that is necessary to provide reliable electronics. I might give you the example of the Bell Telephone transatlantic cable. The cable was under development and in the process of being tested for a period of 20 years before they put it in the ocean. To acquire reliable electronics for a period of 2 to 3 years, it requires almost that period of time to test these electronics, in addition to the development time.

Senator MARTIN. I can visualize this program becoming so far-reaching and of such great importance affecting other agencies, especially in the defense field, to imagine you would all be working together on it in that period of time.

Mr. JAFFE. We are working together on this program.

Mr. CORTRIGHT. Perhaps it might help to mention what Mr. Jaffe means when he says this program is within the NASA, that merely we are organizing the launches, the procurement of the vehicles, and the experiments in cooperation actually with not only the Department of Defense but various commercial communications companies throughout the country.

Senator MARTIN. Yes. I got that from his comment. It helps vastly in what you are doing, and I should think you would necessarily closely cooperate with the commercial agencies as well as defense agencies in your whole program.

Mr. CORTRIGHT. We are doing that. There is a committee structure designed to achieve complete exchange of information and meet the needs of everyone insofar as possible.

Senator MARTIN. Thank you.

Senator STENNIS. Thank you, Senator. All right, Mr. Cortright, who is your next witness?

Mr. CORTRIGHT. The next speaker will be Mr. Benjamin Milwitzky, who will speak on the general subject of geodesy and navigation satellites.

Senator STENNIS. All right, come around. We are glad to have you, sir, and you proceed in your own way.

TESTIMONY OF BENJAMIN MILWITZKY, HEAD, GEODETIC AND NAVIGATIONAL SATELLITES PROGRAM, NASA

Mr. MILWITZKY. Mr. Chairman, and gentlemen; most of my talk will be concerned with the role of artificial satellites in geodesy. Toward the end I will touch upon how satellites can be used as navigational aids.

In the field of geodesy, the satellite can help us in two main areas: First, in connection with the more accurate determination of the size and the shape of the Earth; the second area is concerned with the problem of precisely establishing the distances between continents and the position of oceanic islands which are not known very accurately.

SIZE AND SHAPE OF THE EARTH

There are many reasons why the size and the shape of the Earth are important to us, but I would like to mention just three:

In the first place, any long-range mapping problem involves the shape of the Earth as a fundamental parameter.

Senator STENNIS. Just a little louder, please, sir.

Mr. MILWITZKY. In mapping we need a reference surface or datum on which to project all horizontal measurements and from which all elevations can be figured; this datum is the shape of the Earth. Thus, in the problem of mapping, the basic geodetic reference is a major reason requiring accurate data on the shape of the Earth.

The shape of the Earth also, in a sense, represents the shape of the Earth's gravitational field, and I will come to that later; of course, this has an important bearing on the flight of ballistic missiles, space vehicles, and satellites.

Thirdly, the shape of the Earth gives us extremely important clues to the structure and strength of the interior of the Earth.

When we say "shape of the Earth," or "figure of the Earth," we don't mean the topography of the Earth. What we really mean is the surface of mean sea level, which is called the geoid. On this chart I have shown the geoid in red. As you can see, it appears as a rather wiggly line. This is because the sea level surface is pulled up and down by variations in the mass attractions from place to place.

Now, for mapping purposes, because many calculations are involved, we need a mathematical model to represent the Earth, and for this purpose we generally use an ellipsoid of revolution. This is what you get when you take an ellipse and rotate it about its short axis.

The problem that we run into is this: The force of gravity is normal to the geoid and not normal to our reference ellipsoid, and this difference gives rise to a troublesome error called the deflection of the vertical. We thus find ourselves in a somewhat embarrassing situation. All of our geodetic measurements are tied to gravity, but all of our mapping has to be based on a reference ellipsoid. In order to determine the reference ellipsoid which best fits the geoid everywhere, we have to know the shape of the geoid. We also have to know the differences which exist between these two surfaces at all points.

The fact that the geoid is always perpendicular to the force of gravity means that it is really a surface, not only of the Earth, but of the gravitational field surrounding the Earth, and any distortions of this surface or irregularities in this surface are reflected in similar distortions and similar irregularities in the gravitational field of the Earth. Thus, if we have a satellite in such a gravitational field, its orbit will be distorted or perturbed, as we say, by these irregularities in the gravitational field. And we can use just these distortions to work backwards and determine what is the shape of the geoid that produced the observed perturbations of the satellite orbit.

EFFECT OF EARTH'S SHAPE OR MOTION AROUND IT

To give you an example, I would like to mention two types of perturbations caused by the flattening of the Earth; that is, its oblateness. These are illustrated in the next figure. In the first case, the perturbation is essentially a rotation or precession of the plane of the orbit of the satellite. This shaded area [pointing] is supposed to represent the plane of an ellipitical orbit at a given time. Here at the top of the figure is the apogee, the point farthest away from the surface of the Earth; and here at the bottom is the perigee, the point closest to the Earth. Between the two we have the major axis of the ellipse, which is called the line of apsides.

At a later time, because of the excess pull of the bulge of the Earth each time the satellite comes around, the plane of the orbit has rotated to a new position, shown by the second shaded area. One way to describe this precession is as follows: While the line of apsides maintains a constant inclination to the equatorial plane, the apogee goes around in a circle and the perigee goes around in a circle; thus, the line of apsides swings like this [demonstrating] and the plane of the orbit rotates slowly in space.

A second type of motion due to the Earth's oblateness occurs within the plane of the orbit; this is a motion in which the line of apsides itself rotates slightly from one revolution to the next.

Both of these motions occur at the same time and produce a situation that I have tried to depict here. This is the original plane of the elliptical orbit. After a time, it has precessed around to the new position and, in addition, the apogee, instead of being at the top of the figure, has rotated around to the bottom of the figure.

It is possible, by analyzing such orbital perturbations, to determine improved values for the shape of the Earth.

In the case of the Vanguard I satellite, 1958 B, analysis of just this type of motion yielded the new data on the shape of the Earth that Dr. Fellows mentioned earlier. These data show that the flattening is not quite as much as was previously believed, and this has implications on our ideas regarding the strength of the inner structure of the Earth. It indicates that the Earth is perhaps a little more rigid in its interior than we previously thought.

Other types of orbital perturbations also exist, and can give us further information on the shape of the Earth. For example, it was noticed that the perigee altitude of the Vanguard I was not constant but varied periodically with time; working this data back gave an indication of the finer distortions of the geoid which are superimposed on the basic ellipsoidal shape. I have tried to represent these here. For clarity, they are grossly exaggerated, of course. This is what has given rise to the term "pear-shaped" Earth. It should be noted that actually there are only slight differences in the new shape of the geoid from the basic ellipsoidal form.

Such studies give us additional information about the structure of the Earth, and about the gravitational field of the Earth. The important thing here is that the mantle of the Earth cannot be plastic, if such a "pear shape" exists. If it were completely plastic the shape would have to be symmetrical about all three axis. The fact that it is not is an indication that there is structural strength in the mantle, and calculations based on these observations make it appear that this strength must be just about the same order as that of building brick.

GEODETIC CONNECTIONS

To go on to the second area where the satellite can provide previously unobtainable knowledge about the Earth, let us consider the problem of intercontinental distances and the locations of islands.

As you know, by using the conventional methods of surveying, tied together with astronomical observations, it has been possible to establish in many areas over the Earth, intricate and very accurate geodetic networks. For example, in the North America net, one can

essentially determine distances over 3,000 miles with accuracies of the order of 75 feet. The same is true for points connected to European datum.

Now, these surveying methods, unfortunately, fail when we get to large bodies of water. We cannot use the short base lines over water that we use over land, and so the distances between the continents and the positions of some islands are not very accurately known. The satellite provides us with a powerful tool to determine such distances, since it gives us a triangulation point high up in the sky.

OBSERVATION TECHNIQUES

There are basically three methods which can be used, and I would like to go into those very briefly.

To begin with, if the satellite contains a flashing light of high intensity——

Senator STENNIS. A flashing light, you say?

Mr. MILWITZKY. A flashing light, that is right. It will be equipped with a very high intensity flashing light. The purpose of this flashing light is to permit us to photograph the satellite against the star background. We can obtain the desired geodetic data by any of three separate techniques: The first is the geometric method of simultaneous observations. The second is the orbital extrapolation method. The third may be termed "dynamical analysis." I will try to just indicate what these are.

The geometric method, for example, may be described with the aid of this sketch. The light flashes, and at that instant photographs are simultaneously taken from two points on one geodetic net and two points on the other geodetic net.

In the photographs we have the stars as a background, and the apparent position of the flashing light against the stellar background gives us a line in space which connects the celestial sphere, the satellite, and the observation point. We have here all of the ingredients required to perform a three-dimensional triangulation which will tell us the distances and the orientations of these two nets, one with respect to the other. As you can see, this method does not require information on the orbital characteristics.

The second method is one which you would have to use if you were trying to tie together two nets when it is not possible for stations on both nets to see the satellite at the same time. In such a case, we use the orbit as an extrapolation device to connect an observation here with an observation here.

(At this point, Senator Cannon assumed the chair.)

Mr. MILWITZKY. One of the beautiful features of these techniques is that by using the stars we completely rid ourselves of any dependence the local vertical, and therefore avoid the error that I mentioned before, the deflection of the vertical.

In the third type of analysis, we determine the orbit. We set up the equations of motion for the system in which the gravitational parameters are treated as unknowns, and we calculate what the gravitational terms have to be to account for the observed motion. The

Vanguard I results mentioned previously, associated with the new figure of the Earth, were obtained by this type of dynamical method.

GEODETIC SATELLITE

The last chart is intended to give you an idea of what a geodetic satellite might look like. A relatively simple thing in concept: A fairly high density sphere weighing about a hundred pounds, being perhaps 21 inches in diameter, and equipped with a number of extremely high-intensity discharge lamps. The satellite will contain electrical equipment (capacitors and so on) to operate these lamps, a timer, and a radiobeacon transmitter. These are the antenna. The radiobeacon transmitter will be used for tracking purposes and to provide acquisition data for aiming the cameras. The satellite also contains storage batteries and solar cells to recharge the batteries. Such a satellite is under development at the present time, and we hope to be able to place it into orbit within the next year and a half.

By using satellites of this type, it should be possible to connect all of the geodetic nets and establish a unified datum with an overall accuracy of 60 to 100 feet.

NAVIGATION SATELLITES

Before closing, I want to say just a very few words about navigational satellites.

If a satellite is equipped with a radio transmitter, it gives us an extremely powerful means for providing navigational fixes of high precision which could be used by ships, submarines, and aircraft.

Basically the idea is simple. The satellite will be placed in orbit, and the orbit very accurately determined. The ship or the airplane or submarine would have on board equipment to receive the radio signals, and to make measurements on the radio signals so as to determine the position of the ship with respect to the satellite. Since the satellite position will be known, this gives us the position of the vehicle.

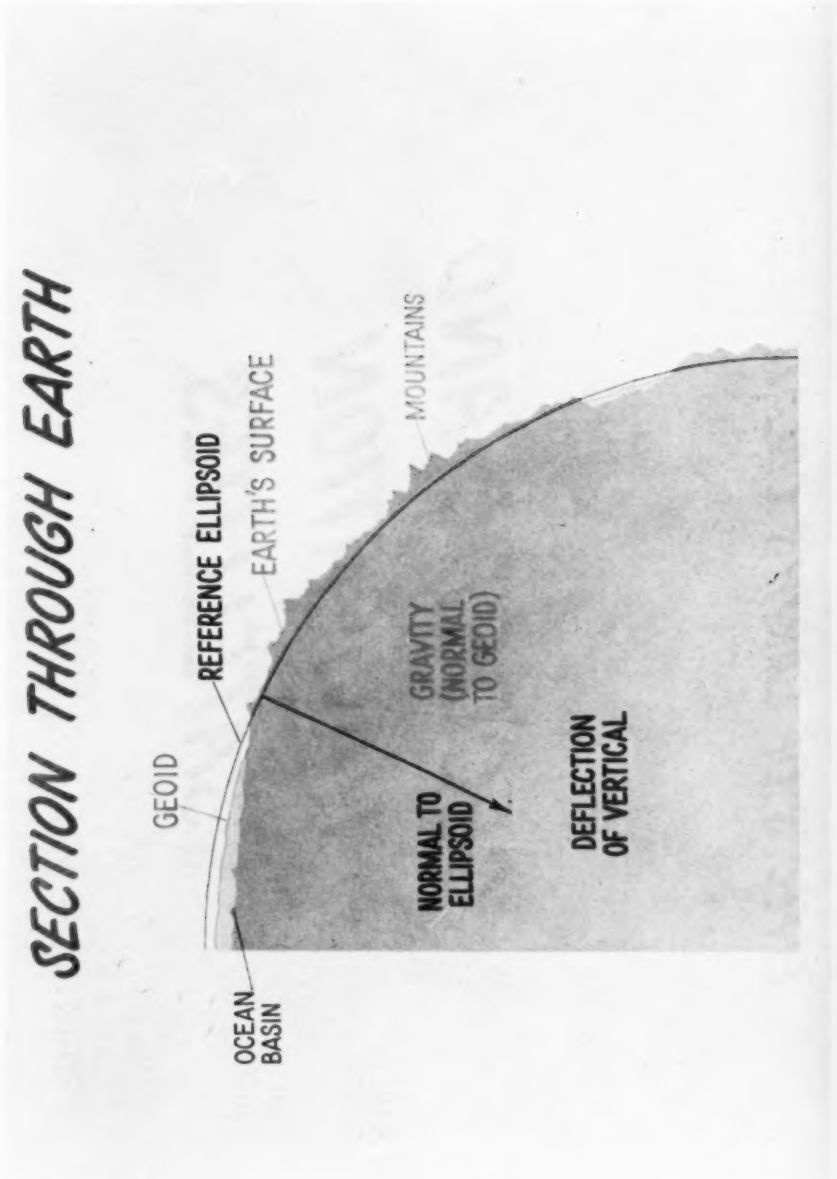
This idea is extremely attractive in connection with inertial navigation systems which may come into quite wide use in the near future. As you know, these inertial systems drift with time, and have to be reset periodically. It appears as though it may be feasible to slave these inertial systems to the passage of satellites so that each time a satellite comes around it will automatically reset the inertial system.

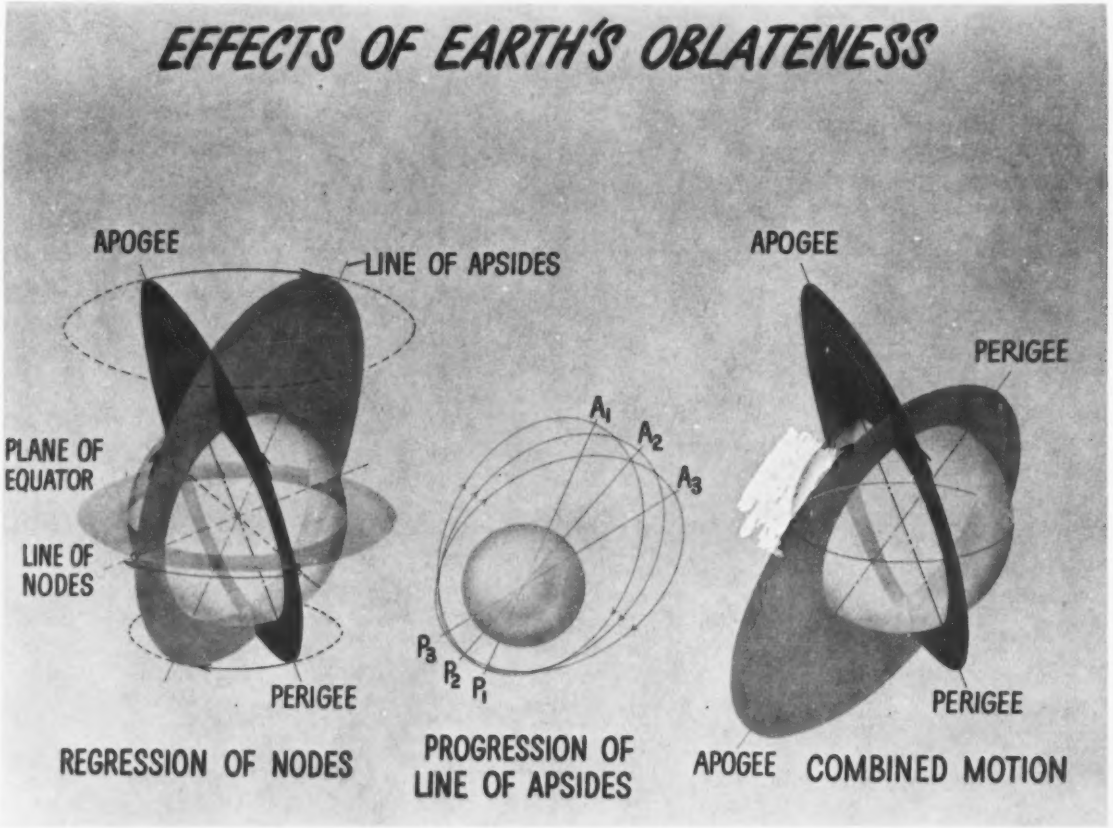
There is, of course, considerable research and development work that has to be done in this area. There are a number of techniques which might be used. We have to determine which are the best techniques and have to develop them to the point where they are practical and reliable.

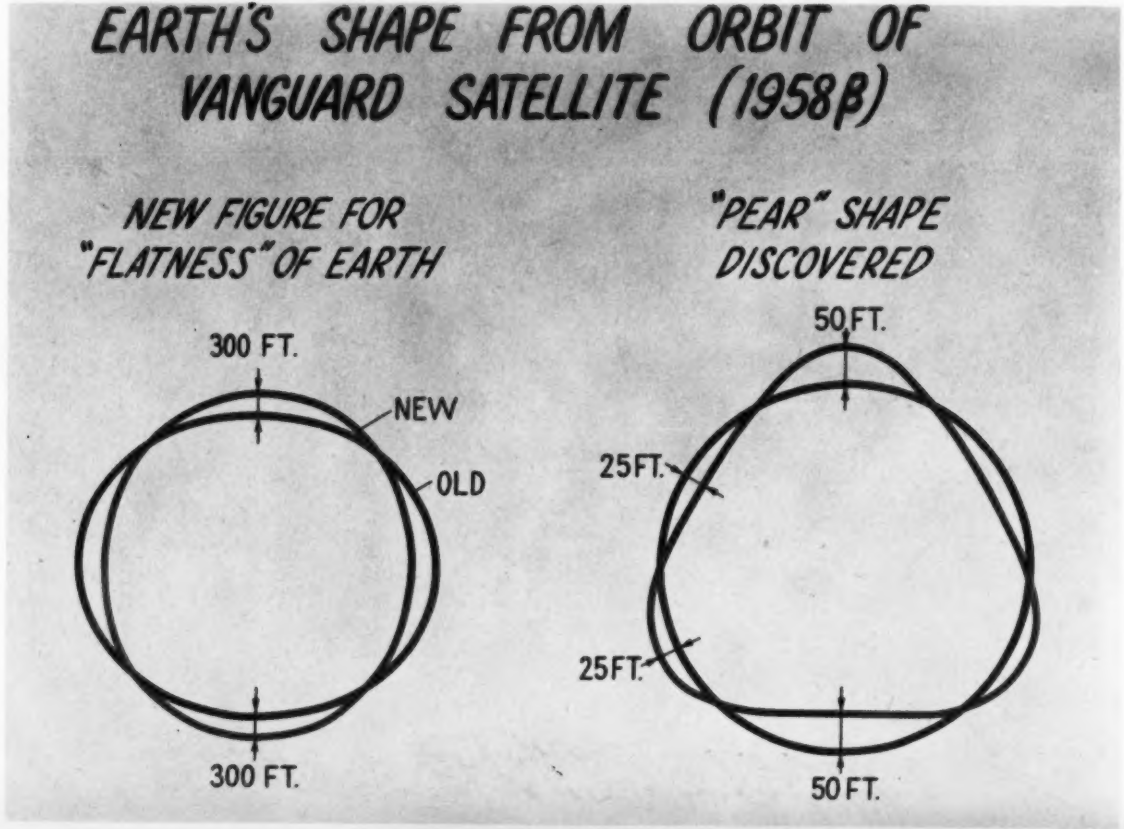
I think the significant thing is this: The indications are that with proper development it may be possible to obtain such a high degree of precision and operational efficiency that a system of navigational satellites might conceivably supersede most of the other navigational aids that we know today.

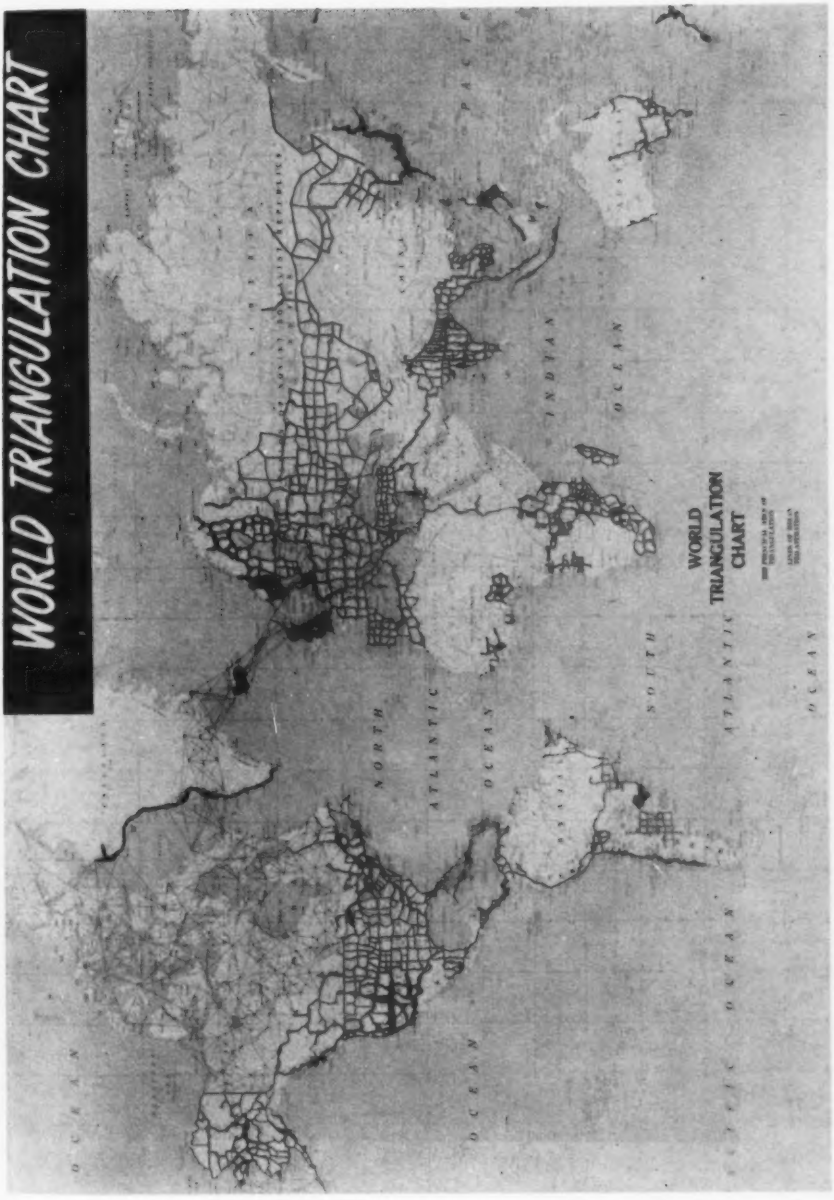
Thank you.

GEODETIC AND NAVIGATION SATELLITES

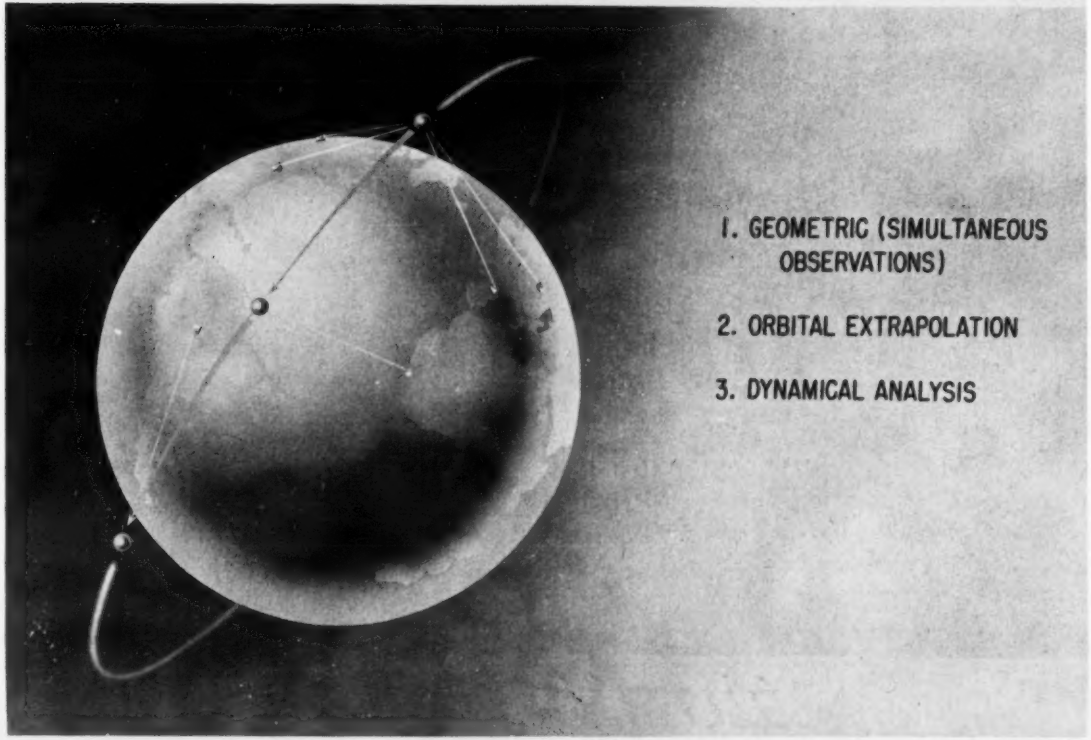

SECTION THROUGH EARTH
GEOID
REFERENCE ELLIPSOID
EARTH'S SURFACE
MOUNTAINS
GRAVITY (NORMAL TO GEOID)
NORMAL TO ELLIPSOID
DEFLECTION OF VERTICAL
OCEAN BASIN


EFFECTS OF EARTH'S OBLATENESS
APOGEE
LINE OF APSIDES
PLANE OF EQUATOR
LINE OF NODES
PERIGEE
REGRESSION OF NODES
A1
A2
A3
P3
P2
P1
PROGRESSION OF LINE OF APSIDES
APOGEE
PERIGEE
APOGEE
COMBINED MOTION
PERIGEE

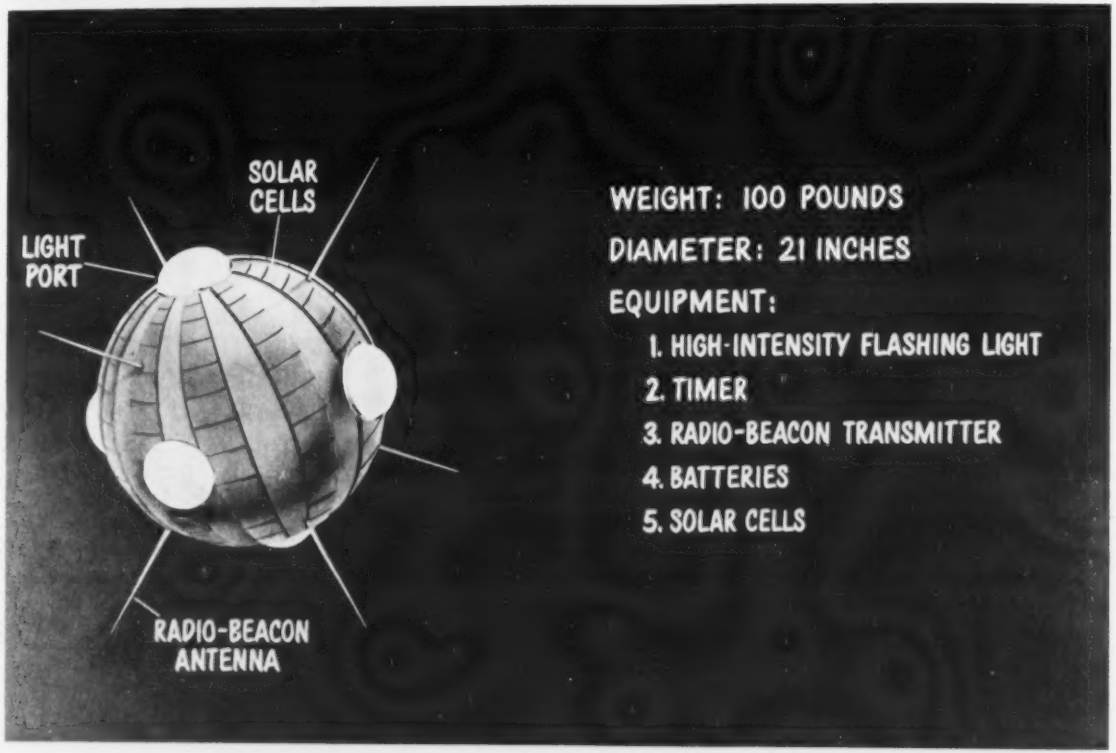

EARTH'S SHAPE FROM ORBIT OF VANGUARD SATELLITE (1958β)
NEW FIGURE FOR "FLATNESS" OF EARTH
300 FT.
NEW
OLD
300 FT.
"PEAR" SHAPE DISCOVERED
50 FT.
25 FT.
25 FT.
50 FT.


WORLD TRIANGULATION CHART
WORLD TRIANGULATION CHART
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
PACIFIC OCEAN

SATELLITE OBSERVATION



GEODETIC SATELLITE



Senator CANNON. Any questions, Senator Martin?

APPLICABILITY OF NAVIGATION SATELLITES TO BALLISTIC FIELD

Senator MARTIN. This tying of the satellite to the inertial guidance system and applying that to the ballistic field, would you have to have the cooperation of the target to do accurate range-finding to a given spot? I am getting you out in pretty deep water there, but I have a purpose in asking this.

Mr. MILWITZKY. I am assuming that we have first done all this and have determined the intercontinental distances so that we know where the target is.

Senator MARTIN. That is correct. We talk about the speed and thrust on the ballistic missile. One foot at 3,000 makes quite a difference. I want to know how we go in and get the impact.

Mr. MILWITZKY. In the case of a ballistic missile, the part of the flight during which the missile is guided is so short that the inertial system does not drift very much. This is really the key to it. So this really would not be applicable to ballistic missiles, and would not be necessary.

But navigation satellites could be useful, for example, for submarines, ships, and aircraft, particularly if you had an atomic-powered aircraft which, say, was circling the earth or was on very long missions for days.

Senator MARTIN. Can this satellite system be used to establish exact ranges to points which are not cooperative with you?

Mr. CORTRIGHT. May I answer that? If the point actually fell within one of the known nets, and you tied the end of the net which is in, say, cooperating territory to your own net, then the answer is yes. If it is an unsurveyed point, the answer is no.

Senator MARTIN. Well, there are points which are unsurveyed and not exactly cooperating with us, and we could not look to this as a means of pinpointing a range.

Mr. CORTRIGHT. No, sir. This actually concludes the discussion——

Senator CANNON. I have just one question. Will this geodetic satellite give us more accurate information on any points in Russia, very plainly speaking? I think that is what Senator Martin had in mind.

Mr. CORTRIGHT. Well, as you noted on the map, the net established by the survey has extended into a portion of Russia, and insofar as we would tie that net better to our own, the answer is "Yes." I think Dr. O'Keefe might have a comment here.

Dr. O'KEEFE. The answer is very definitely "Yes." I do not know whether we can give numbers here without getting into classified areas, but the answer is very definitely true. It would be of major assistance in this problem.

Mr. CORTRIGHT. Is this within the scope of the present survey net, or even beyond where that reaches?

Dr. O'KEEFE. This is within the scope of the present survey net, but a comparison of the present survey net will show at once that the great majority of the things which one might imagine to be targets in the U.S.S.R. lie within the data on which we have accurate maps and survey data. The great majority.

Mr. CORTRIGHT. Thank you.

Senator CANNON Thank you.

Senator MARTIN. It certainly would be a far step ahead of what we have at the present time.

Senator CANNON. It may be that we are getting on the border of classified information there, and if we are, that will be pursued in executive session later on. Mr. Cortright?

Mr. CORTRIGHT. Well, this might, if you have no further questions on meteorological communications, navigation, or geodetic satellites, be a good breakpoint if you want to take it.

The next section will be led by Mr. Frank Smith, who will lead the discussion on supporting ground systems.

Senator CANNON. Mr. Smith, I think we might take a 5-minute recess and be prepared to proceed at that time.

(Short recess.)

Senator CANNON. All right. May we proceed. Mr. Smith, you may proceed.

Mr. SMITH. Mr. Chairman, one of our members has not shown up yet. We expect him momentarily. In the meantime, we have a substitute. I would like to introduce: Mr. Leonard M. Cormier, Mr. John Mengel, and I am Frank Smith.

Senator CANNON. Mr. Smith, the usual practice of the committee is that the witnesses are sworn. Have these gentlemen been sworn earlier?

Mr. SMITH. We have not.

Senator CANNON. I wonder if you would all stand, please, and raise your right hand.

Do you, and each of you, solemnly swear you will tell the truth, and nothing but the truth, in this hearing, so help you God?

Mr. SMITH. I do.

Mr. MENGEL. I do.

Mr. CORMIER. I do.

Mr. SMITH. This portion of our presentation is on the ground support systems which are needed to carry out the various satellite space vehicle programs which have been discussed thus far. In getting into talking about the more romantic parts of the approach to the moon and approach to Mars and Venus, and so forth, often the very necessary supporting ground instrumentation and ground facilities are overlooked. These three talks will cover these facilites.

I might interrupt right here, if I may, since Dr. Hagen has just shown up, and if you would like to swear him in, then——

Senator CANNON. We might wait until he is ready to testify.

Mr. SMITH. Actually, he was supposed to be on the program first, and we will put him on this minute.

Senator CANNON. Dr. Hagen, it is good to have you with us again today.

Do you solemnly swear the testimony you are about to give will be the truth, the whole truth, and nothing but the truth, so help you God?

Dr. HAGEN. I do.

(The biographical sketches of the witnesses follow:)

FRANCIS B. SMITH, CHIEF OF TRACKING PROGRAMS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Francis B. Smith, Chief of Tracking Programs, National Aeronautics and Space Administration, is responsible for the planning, installation, and coordi-

nation of the NASA ground instrumentation facilities which will be established to support NASA flight programs.

Smith is a native of South Carolina. He earned his bachelor's degree in electrical engineering in 1943 from the University of South Carolina, where he was named Phi Beta Kappa. From 1944 to 1946 he served in the U.S. Navy, engaged in airborne radio and radar work.

In 1947 Smith joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in the Instrument Research Division, Langley Aeronautical Laboratory. He later was made head of the Pilotless Aircraft Instrument Research Branch.

He was responsible for the development, procurement, installation, and operation of the various telemetry, control, and radar tracking instrumentation systems that supported the NACA high-speed rocket test program at the Wallops Island, Va., test station. In addition, he was responsible for the development of the instrumentation systems used in the D–558, the X–1, X–2, and X–15 high speed research airplanes.

Mr. and Mrs. Smith (the former Hazel Long) and their three children live on Route 2, Queens Lake, Williamsburg, Va.

JOHN P. HAGEN, CHIEF, VANGUARD DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John P. (Peter) Hagen, the former Director of the Earth Satellite Program—Project Vanguard, became a member of the staff of the National Aeronautics and Space Administration on October 1, 1958, when the Vanguard program was transferred from the U.S. Naval Research Laboratory to the NASA.

Dr. Hagen was born in Nova Scotia. He earned a bachelor of arts degree at Boston University in 1929; a master of arts degree from Wesleyan University in 1931; and a doctorate in astronomy at Georgetown University in 1949.

Dr. Hagen was a research scientist at the Naval Research Laboratory from 1935 until he joined the NASA staff. His fields of research included properties of quartz crystals, microwave radio magnetrons, semiconductors, parabolic antennas—all directed toward the extension of radar techniques. This research work enabled Dr. Hagen to lead development of techniques resulting in an automatic ground speed indicator for aircraft.

He worked on microwave communications, centimeter wave radar, communications, and countermeasures during World War II. For early work in radar, he received a Presidential Certificate of Merit.

After the war, he headed NRL's Radio Physics Research Group. Under his direction, this group conducted research on properties of metals at low temperatures, and developed, in 1950, what still is the most precise radio telescope in the world which enabled discovery of absorption of hydrogen clouds in our galaxy. He also organized and led eclipse expeditions to study the sun, optically and by radio means.

Dr. Hagen became head of NRL's Atmosphere and Astrophysics Division in 1954. He supervised and administered a broad program of upper atmosphere and astrophysical research. In the fall of 1955, he was appointed Director of the Vanguard earth satellite program, one phase of the U.S. participation in the International Geophysical Year.

Dr. Hagen has served on the Panel on Radio Astronomy, National Science Foundation; the Solar Activity Technical Panel of the U.S. National Committee of the IGY; chairman of the Associated Universities Steering Committee for Radio Astronomy; and lecturer at Georgetown University. He is a Fellow of the Institute of Radio Engineers and the American Academy of Arts and Sciences; and a member of the American Astronomical Society, International Astronomical Union, Washington Academy of Sciences, International Radio Scientific Union, and Sigma Xi.

The Chief of NASA's Vanguard is married to the former Edith Soderling. Dr. and Mrs. Hagen and their two children, Peter J., 17, and E. Christopher, 14, live at 3001 Second Street, North, Arlington, Va.

JOHN T. MENGEL, HEAD, SPACE TRACKING SYSTEMS BRANCH, VANGUARD DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John T. Mengel, head of the Space Tracking Systems Branch in the Vanguard Division, joined the National Aeronautics and Space Administration when the new agency became responsible for the Vanguard scientific earth satellite program in October 1958. Previously he was a member of the staff of the U.S. Naval Research Laboratory.

Mengel is a native of Ballston Lake, N.Y. He received his Bachelor of Science degree in physics from Union College in 1939. During the next year he was an assistant instructor in physics at Lafayette College. From 1940 to 1942 he was engaged in vacuum tube development at General Electric. During the following 4 years he was with the U.S. Navy's Bureau of Ships in the development and evaluation of special detection devices.

In 1946 Mengel joined the staff of the U.S. Naval Research Laboratory in the Rocketsonde Research Section. He was responsible for the design and fabrication of the first research nose shell to replace warheads of V–2 rockets fired in this country for high-altitude research.

Mengel was named head of the Electronics Instrumentation Section in 1947, and in 1954 became Coordinator of Guidance in the Rocket Development Branch. In 1955, he was appointed head of the Tracking and Guidance Branch of Project Vanguard.

Mengel is a senior member of the Institute of Radio Engineers, and a member of the American Rocket Society.

Dr. HAGEN. I apologize for walking in at this late moment.

TESTIMONY OF DR. JOHN P. HAGEN, CHIEF, VANGUARD DIVISION, NASA

Dr. HAGEN. In the formulation of a national space program, of necessity the first consideration was given the problems of obtaining the propulsive power required to place satellites in orbit and to launch space probes.

This is an interesting and challenging program, and has received so much attention that little has been said about the ground installations which will be necessary for the optimum utilization of space vehicles. An effort is made here to give some feeling for the factors involved in establishing ground installation requirements as dictated by the program itself.

For the launching, the tracking, the acquisition of data, and the rapid computational effort attendant to the utilization of space vehicles, both of the earth satellite type and for deep space probes, a complex ground installation is required.

ELEMENTS OF SPACE FLIGHT LAUNCH CONTROL AND TRACKING NETWORK

On our first chart we see the elements of such a far-flung installation.

First, there must be a launching facility. Associated with this there must be a tracking network adequate to the control of the vehicle during the launching phase. This is for safety and trajectory trimming requirements. There must also be far-flung tracking networks, both electrical, as here, and optical. These are to acquire the space package after it is inserted in its path, to keep track of it during the time it is performing its mission. There must also be a telemetering capability associated with these networks to collect the scientific data acquired by the vehicle during its mission. This actually is the tracking over here, and here is the telemetering, and it must be so set up

that we can contact the vehicles at the proper times. There must be a communication network with its center here to tie together the various data-collecting stations and to bring each of these stations into contact with the central control station here at the Beltsville Space Center. Finally, there must be a computing center where ephemerides of the satellites and complex data reduction may be accomplished.

The ground installation requirements for the utilization of space vehicles is presented now because of the considerable lead time and budgetary support which will be required to provide for the engineering and construction of these facilities, and for the assembling and training of the personnel required to staff them. I will describe now the launch phase requirements, Mr. Smith the worldwide tracking and data acquisition, and Mr. Mengel the communications control center and orbit computation and prediction requirements.

THE LAUNCHING COMPLEX

The first consideration in the definition of the reqiurements of a launch complex or complexes is the size and type of vehicles to be employed.

The NASA space program as currently defined will involve the launching of the following types of space vehicles:

First, earth-circling satellites at various altitudes, using vehicles which will have thrusts of from 30,000 pounds to 150,000 pounds.

Secondly, the launching of larger earth-circling satellites using vehicles having thrusts in the range of 150,000 pounds to about 6 million pounds.

The launching of space probes using vehicles having initial thrusts in the range of 150,000 to 6 million pounds is the third objective.

POLAR, EQUATORIAL AND INTERMEDIATE ORBITS

As for the orbits that are planned, the next chart or this chart shows the various types of satellite orbits required to carry out the Space Administration mission.

Three different orbits are shown here. The first is an equatorial orbit in green, where the satellite flies in approximate circles about the earth, just above the Equator.

The second type is a polar orbit, which is inclined at 90 degrees to the equatorial, and where the satellite circles the earth from pole to pole with the earth turning onto the orbit.

There is a third type which has been used in the past, and will be used in the future extensively. This is an orbit in an intermediate inclination which is then between the equatorial and the polar.

For some scientific purposes this inclined orbit will be optimum and will be provided, therefore, in many cases. The present satellites, both American and U.S.S.R., are in this type orbit.

Shown in the chart is a schematic of an orbit for which the vehicle was launched at Cape Canaveral in a southeasterly direction to attain an orbit inclination of about 30 or 40 degrees here to the Equator.

In order to launch a satellite into a polar orbit from within the continental United States, it is clear from the chart that we are

limited in our operations to the west coast; that is, if we are to obey the restriction that the launching vehicle shall not pass over inhabited areas of the earth.

As you can see, if we attempted to launch in a polar orbit from Canaveral, we would pass over these inhabited areas here; or if we launched northward, above New York City and parts of Canada.

For an equatorial launch, a site has not yet been chosen. This launching site, however, can be transportable one set up on an island near the Equator, or possibly might be on a ship.

LUNAR OR PLANETARY TRAJECTORIES

The next chart shows a schematic of a possible lunar or planetary probe trajectory. In its early stages it resembles very closely that of a satellite. The principal difference between a deep space probe trajectory and a satellite trajectory is one of velocity. The two trajectories are exactly similar up to this point. The deep space probe goes out at a greater velocity and therefore escapes the Earth.

For the deep space probe, the vehicle is required to attain a velocity sufficient for escape.

Now, to take advantage of the rotational velocity of the earth, it is again advisable to launch the vehicle of this sort from as low a latitude as possible, where the rotational velocity is greatest.

For the immediate future and most possibly for many years to come, the launching vehicles used in space work will have to be multistage rockets. As indicated earlier, the ground installation requirements have to accommodate vehicles of an ever-increasing thrust level. Launching facilities will have to be designed to prepare and to service these huge devices. The thrust levels specified for the larger Earth-circling satellites and for space probes have been indicated to be as large as 6 million pounds. As an indication of the problems here, the heat energy involved in the launching of one of these large vehicles having 6 million pounds thrust has shown that in bringing it to an altitude of 50 feet above the launching pad, enough heat is generated to boil away 10,000 gallons of water.

TYPICAL LAUNCH FACILITIES

The next chart shows the major functions which must be performed by and the equipments which must be found at the launching site. Attention is invited first to the facilities which must be employed in the launching of the vehicle.

First, there is the launching pad, which is capable of supporting the vehicle during its time of preparation. This pad must be so equipped that it can handle and deflect the flame at the time of launching. It must also be instrumented to handle servicing equipment and provide for the necessary electrical, mechanical, and hydraulic connections involved.

Near the pad is shown a servicing structure, this gantry, which can be moved back and forth on rails. This crane is brought over the vehicle and encircles it during its assembly and installation of its equipment and during prelaunch testing. When the vehicle is ready for launching, the gantry is rolled away.

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Nearby there is also a blockhouse. It is so constructed that personnel are protected against accident. It is in this blockhouse that all of the complex equipment required in the control of the operations within the vehicle during the launch preparations is located. It is also from this blockhouse that the actual firing is performed.

Several miles away, up here, is usually found the hangar. It is to the hangar that the vehicle is first delivered when it is brought to the launch site. In the hangar the vehicle is inspected for any damage during transport, and is readied for installation in the pad. In the hangar also there are workshops to provide for the repairing or replacement, as needed, of the electronic or mechanical equipment in the vehicle. Upon completion of the hangar operations, the vehicle is presumed ready to launch and is taken to the launch pad. The hangar is the home base of the launch crew. It is here that the telemetered data from the flights are analyzed and monitored during flight.

During the vehicle launching operation, the whole of the launch complex is tied together at one place in this central control. This central point is several miles, again, from the launch pad, but is closely linked by communications to the hangar, the blockhouse, the launch site, to the local tracking and telemetering facilities, and to all of the down-range stations. During the launching operation, all information is fed into this central control point, and upon the basis of this information the range officer determines that the range is ready to accept the vehicle when it is launched.

After the launching crew has brought the vehicle to the point where it is ready for the firing signal, and when an O.K. has been given by the range control officer at central control signifying that the range is ready to accept the vehicle, the launch is effected. Also, located adjacent to the launching area is a telemetering pad, down in here, where one finds the electronic equipment necessary to a preliminary determination that the rocketborne transmitting equipment is functioning properly. At this location there is also a computer which will give a quick reduction of the telemetered data so that the crew can have an immediate understanding of the operation of the vehicle during the early phases of its flight.

Such an integrated space launching facility has now been set up at the Atlantic Missile Range.

COMMAND AND ACQUISITION NETWORK GROUND STATIONS AND DOWN-RANGE SUPPORTING FACILITIES

The installation will also be affected by the type of trajectory which is employed. This next chart shows a typical space vehicle trajectory, and will serve to illustrate some of the problems which must be solved.

The vehicle is usually launched vertically from the pad, and is allowed to fly vertically until it attains some velocity, and then the orbit is inclined slightly to move the vehicle away from the launching facility. It is allowed to proceed along this path through the denser portion of the atmosphere, and then it is programed over into the desired direction. After it gets up to a height of a hundred miles or so, it begins to program over. The direction in which it is programed is usually toward the east to take advantage of velocity. With the ex-

haustion of the propellants in the final stage, the satellite is on its way toward an orbit out here.

Its mission might be extraterrestrial; that is, it might shoot off in the direction of the Moon or a planet. Or it can be an Earth-circling satellite, for which it has a somewhat lower velocity, but still high enough to balance out the gravitational forces of the Earth.

The thing which should be noticed here is the scale. The launching operation starts at this installation at Cape Canaveral, and it continues for a distance of approximately a thousand miles down-range. Throughout the whole of this launching operation, the launch crew must maintain contact with the vehicle, as shown in our chart. The trajectory is shown somewhat to scale against the curved Earth.

The location of the various down-range stations which must be outfitted to provide a sufficiently complete range to launch such a vehicle are indicated. Starting at the launch site at Cape Canaveral, there must be telemetry stations capable of receiving the signals transmitted from the rocket during the operation of the first and of the second stages at this point.

There must also be a minitrack or a doppler radio device which is capable of measuring the instantaneous velocity of the vehicle during its entire trajectory. Also near the launch pad we have installed a powerful and accurate tracking radar which is capable of following the flight of the vehicle at least through the completion of the second stage operation. Associated with this radar is a large, complex electronic computer so that the computed predictions of the trajectory can be given to the launching crew in essentially real time in order for them to make the necessary decisions which affect the flight of the vehicle, and these must be effected in this area.

Going down the map to the island of Grand Bahama, there is a telemetry facility, a second tracking radar, and a command transmitter. It is through this command transmitter that the flight of the vehicle may be varied. Not all of the vehicles are planned in the same way. Many of vehicles, such as Vanguard, have an inertial guidance and a control system which is contained in the vehicle itself. In the vehicle and in the ground facility, there is provided, however, equipment which allows the ground crew to modify the direction of flight if they determine that the operation of the vehicle is such as to require it.

The next down-range station is on San Salvador, down in here, and this is equipped with a telemetering station and another set of command transmitters.

Further down the line, there is a station on Grand Turk over in here. Here again, detailed information is gathered from the vehicle and a minitrack ground station capable of tracking the flight of the vehicle is located. Also at Grand Turk, there is a command transmitter which is used as the last chance station to send signals directing the separation and the ignition of the third stage of the vehicle.

Out on Puerto Rico there is an additional telemetry station, and on Antigua, an island some 1,100 or 1,200 miles downrange, there is a prime minitrack receiver. This operates in conjunction with Grand Turk to gather telemetry and doppler data on the flight of the third stage.

COMPLEX FACILITY REQUIRED FOR EACH LAUNCHING SITE

Now, the instrumentation plan shown here is the one which was developed for use in the launch of the Vanguard vehicle, and should not be significantly different from the type of instrumentation required for the proper launching of any future type of vehicle. The trajectory and the sequence which the vehicle must follow are complex. They must be carefully monitored, and it must be possible to send commands to the vehicle at any time during the powered flight, during this thousand-mile trajectory.

A facility such as has been described above, which consists of all of these elements at the launching site, and the complex telemetering, radar, transmitting, and tracking stations stretched out along the long trajectory is required for each launching site. We presently have such a facility at Cape Canaveral. A similar one will be required at the Pacific Missile Range at Point Arguello in California. In the providing of such a facility at the Pacific Missile Range, we will find, no doubt, a great deal of hardware already installed by the services, and it is hoped that much of it will be of use to the space program. However, we must look forward to modifying or adding to the installation just as we did at Cape Canaveral to make it suitable for handling the NASA space vehicles.

NASA has also an installation at Wallops Island in Virginia. Here small space vehicles can be launched, but the larger liquid rockets are not suited for launching at this location. As has been indicated, the launching facilities which will be required for the heavier launching vehicle are not now in existence, although the Cape Canaveral and Point Arguello locations are suitable for the meeting of such orbital requirements.

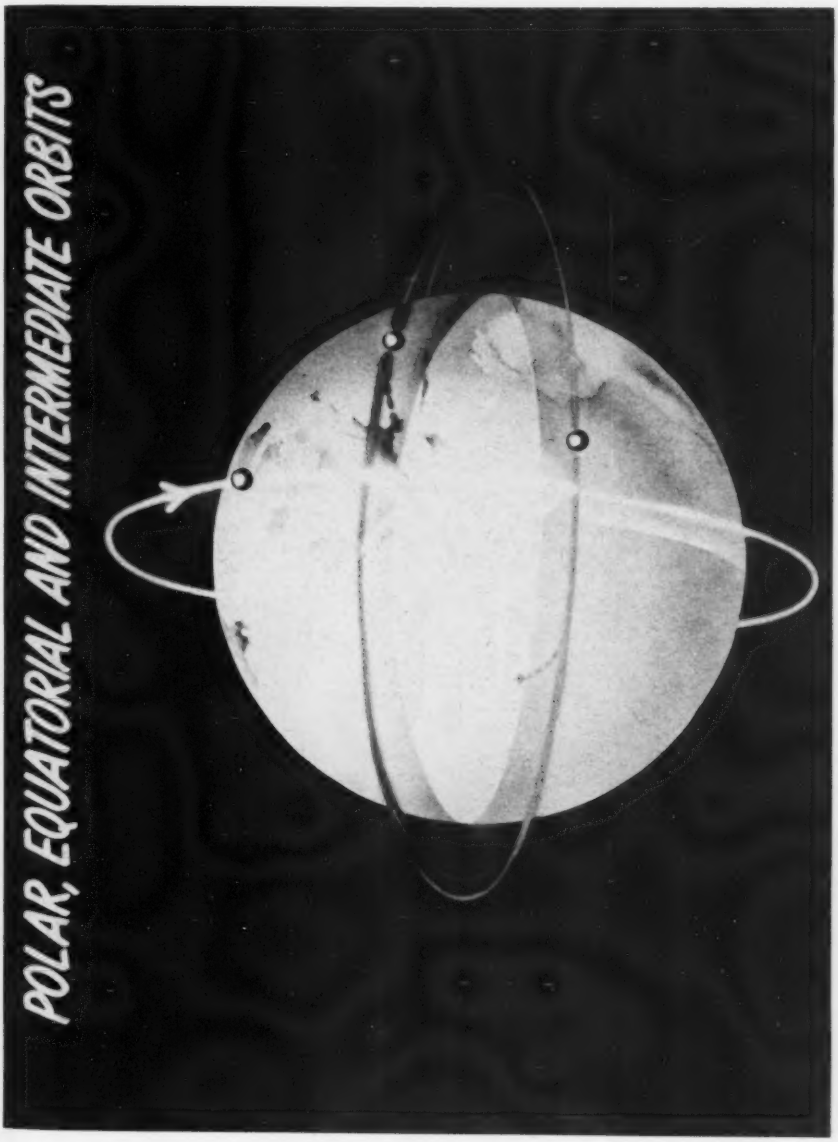
The command and acquisition network at Cape Canaveral should be adequate, with little modification, to the requirements.

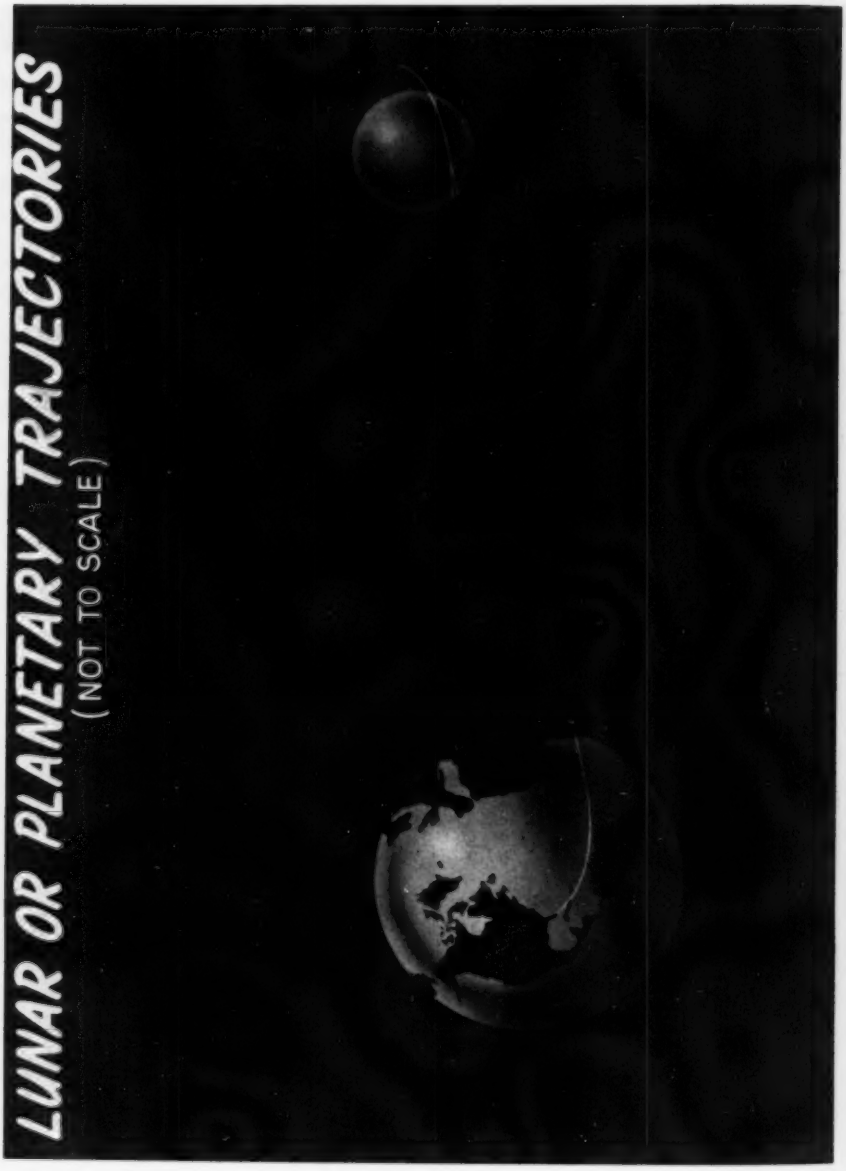
The command and acquisition network at Point Arguello must be generated, utilizing as much as possible of the Pacific Missile Range instrumentation.

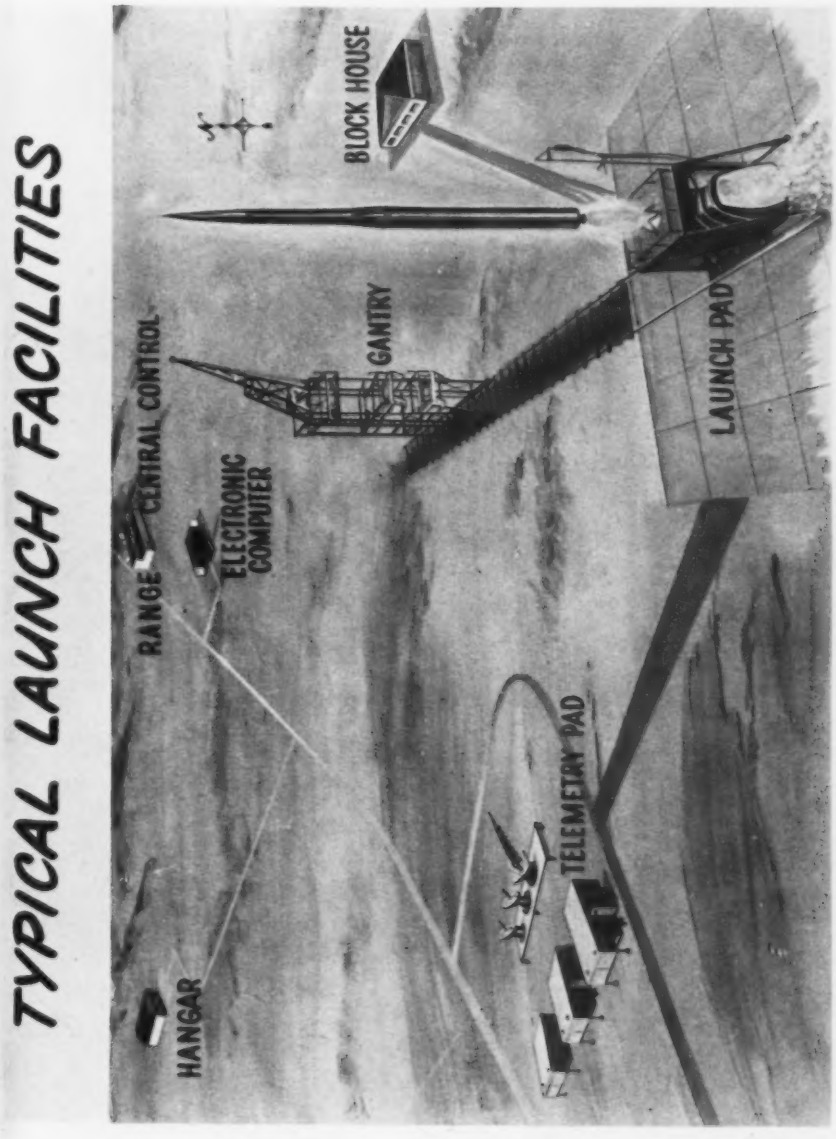
Thank you.

SUPPORT SYSTEMS
LAUNCHING AND INSERTION FACILITIES

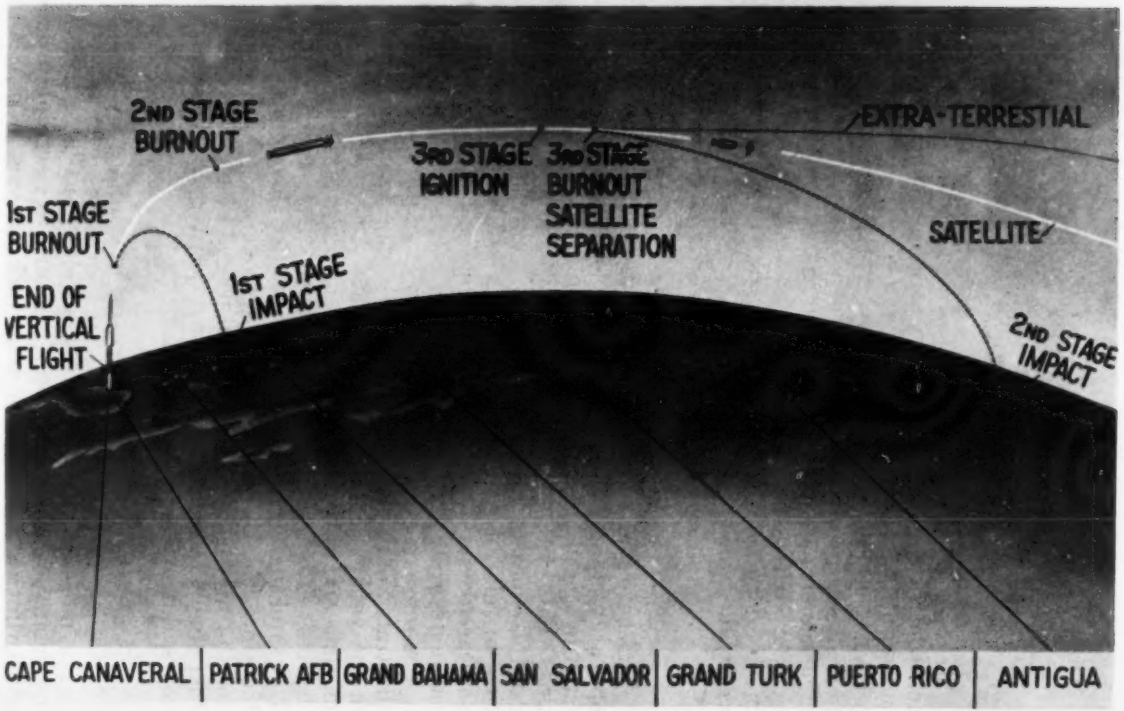
ELEMENTS OF SPACE FLIGHT LAUNCH, CONTROL AND TRACKING NETWORK
5 CONTROL CENTER NETWORK CONTROL COMPUTING
2 TRACKING -ELECTRONIC OPTICAL
3 DATA COLLECTING
4 COMMUNICATIONS AND DATA TRANSMISSION
1 LAUNCHING AND INSERTION


POLAR, EQUATORIAL AND INTERMEDIATE ORBITS


LUNAR OR PLANETARY TRAJECTORIES
(NOT TO SCALE)


TYPICAL LAUNCH FACILITIES
HANGAR
RANGE CENTRAL CONTROL
ELECTRONIC COMPUTER
GANTRY
BLOCK HOUSE
TELEMETRY PAD
LAUNCH PAD

GROUND STATIONS AND DOWN-RANGE SUPPORTING FACILITIES



Senator STENNIS (presiding). Doctor, we are very glad to have you here, indeed, and we hope to have some questions for you in a few minutes. All right, gentlemen, whom do you have next? Mr. Smith?

Mr. SMITH. Yes, sir.

Senator STENNIS. All right. Thank you.

TESTIMONY OF FRANCIS B. SMITH, CHIEF OF TRACKING PROGRAMS, NASA

Mr. SMITH. Dr. Hagen has described the tracking and guidance and control facilities which are necessary in the launching area to successfully place the vehicle in the desired orbit. Once the desired orbit has been accomplished, it then becomes necessary to observe or to track the satellite or space vehicle periodically in order to determine the elements of the orbit and in order to measure the perturbations or changes in the orbit. This tracking can be done normally in one of two ways: either by electronic means or by optical means, as are illustrated here.

PHOTOGRAPHIC SATELLITE TRACKING

This next chart shows one of the large Baker-Nunn cameras used for optical tracking. This actually tracks by taking a photograph of the satellite against the star background. Such a photograph looks like this. This is the trace of the satellite, and these are the stars. By carefully measuring the position of a satellite at various instants of time in relation to the stars, it is possible to determine its position very accurately. Using this information, it is then possible to calculate its orbit.

The present locations of the large tracking cameras just shown are illustrated on this chart. There are some 12 of them that are located at the various countries shown here. You will note that they are all concentrated between northern and southern latitudes of about 35 degrees. The reason for this is that they were positioned to track U.S. satellites which had an inclination of 35 degrees or better, and so, therefore, they would not provide coverage which would be needed for the higher inclination satellites. These cameras are limited in that they are useful only during dawn or dusk conditions, and of course during clear weather conditions.

MINITRACK STATIONS

For more universal tracking which is available day or night and under any weather conditions, we turn to electronic means, and this chart illustrates one of the minitrack stations, which is the primary electronic means of tracking. This station operates by receiving a radio signal from the satellite which is transmitted by a very lightweight transmitter in the satellite, and the position is determined by a comparison of the signals which are received by the various antennas which make up the station. The antennas are illustrated in the closeup photograph shown at the bottom of the chart here. This method is not quite as accurate as the optical method, but the data

read-up methods are much faster and it is useful under any weather conditions.

The locations of the minitrack stations are illustrated on this map; locations of present stations. There are some 12 stations, and here you will notice that most of the stations are located in a north-south line, again between 35° south latitude and 35° north latitude, approximate locations, the purpose or the reason for these locations being that we were trying to track satellites which were in low inclination orbits. A satellite which has an inclination of, say, 30° would cross over one of the stations in this net at least once each orbit. The other two stations in Australia and south Africa are useful in giving a better determination of the initial orbit. When we fire southeast from Canaveral, we pick up this station and the Australian station.

Now referring back to the original chart for a moment, another function that must be provided by the ground network is that of data collecting. All U.S. satellites, at least, have a transmitter, a so-called telemetry transmitter, which sends down scientific information or possibly TV information which must be received by the ground station. Since the power transmitted is very low, it requires special, very sensitive receiving equipment and high gain antennas on the ground for this purpose.

LUNAR PROBE ANTENNA

This chart illustrates two types of antennas which are used. This is a large parabolic antenna, the purpose of the dish shape here being to reflect the radio signals back to the antenna proper, which is located at the focal point here. This particular antenna is 60 feet in diameter. Another simpler type, but somewhat less effective, is the so-called quadrihelix, which also gives you more gain than you would get with an ordinary type of receiving antenna. In both cases these antennas must be pointed directly at the satellite as it passes overhead, because they are insensitive if the satellite gets out of the beam of the antenna. I do not have a chart showing the location of these antennas. There are a few stationed around which for the most part have been borrowed from the missile ranges. There are two in Hawaii, there is one in Florida, there is one in California, and there are a few others downrange in the Atlantic missile range.

The discussion thus far has been regarding existing facilities. On the next two or three charts, I would like to discuss additional facilities as we are contemplating installing to give us better coverage for some of the vehicles which will be flown in the future.

HIGH INCLINATION ORBITS

This chart illustrates satellites which have a higher inclination—in this case, I believe it is 51 degrees—and you will note if we traced out each of these passes here, we would see they do not pass very close to the existing tracking stations. The same thing can be said of the satellites placed in polar orbits. This illustrates one launched southward from Point Arguello, or the Pacific missile range, which would pass south here and then back north over here, south over here again, and it would make several passes before it would be picked up by either the south African or possibly later the Australian station.

In order to help fill the gaps, the NASA is proposing to install four additional stations in the general areas illustrated on the map. The specific areas have not been chosen. The general areas being Alaska, the north-central part of the United States, Newfoundland, and the European area. The other station shown here is one which has been relocated from Cuba to Florida.

GOLDSTONE ANTENNA

Another type of program which is being undertaken, of course, is the lunar probes or, later on, the planetary probes, and here again a special type of equipment is required in the form of large-, very large-diameter tracking antennas. This is the 85-foot tracking antenna which is located at Goldstone. It is even larger than the one previously indicated.

Senator STENNIS. Where is Goldstone?

Mr. SMITH. Goldstone, California. It is near Camp Irwin.

The problem here being that instead of trying to receive the weak signals from satellites which may be a few hundred or a few thousand miles away at most, we will be trying to receive signals from space probes which will be in the order of millions of miles away, so that even larger antennas are required.

DEEP SPACE COVERAGE FROM THREE STATIONS

Ideally, to track a deep-space probe on a 24-hour-a-day basis, a minimum of about three stations would be desirable, located approximately 120 degrees apart in longitude; and this chart illustrates that if one had three such stations, once the space probe had gotten a distance of a few thousand miles from the Earth it would be visible from one or the other of the stations continuously.

The two sites we have chosen to operate along with the existing California station are South Africa and Australia, and we have plans for installing additional tracking antennas of this type at those two locations.

MERCURY ORBITS

There is one final program which will require additional tracking facilities, and this is the manned-satellite program. The requirements of this program are particularly severe for at least two reasons; one being that there is a man aboard and the reliability of the tracking facilities and control facilities must be as near perfect as they can humanly be. The second is that this satellite, unlike most of the others launched to date, will not remain aloft for a very long period of time. Present plans call for launching it northeastward from Canaveral and allowing it to go around once, twice, and possibly three times, and then for a recovery in the Atlantic area.

In tracking of the more usual type of earth satellite, it normally requires a few orbits, two or three or four, before the orbit can be thoroughly established; but in this case it will be essential to establish the orbit immediately once it is injected, so that you know exactly where the vehicle is going and exactly where it will come down. For these reasons, additional facilities are required. The type fa-

cilities which will be needed are tracking radars of the FPS–16 type, and it is anticipated that tracking radars will be installed on Bermuda, Hawaii, and in the south-central part of the United States.

TRACKING RADAR

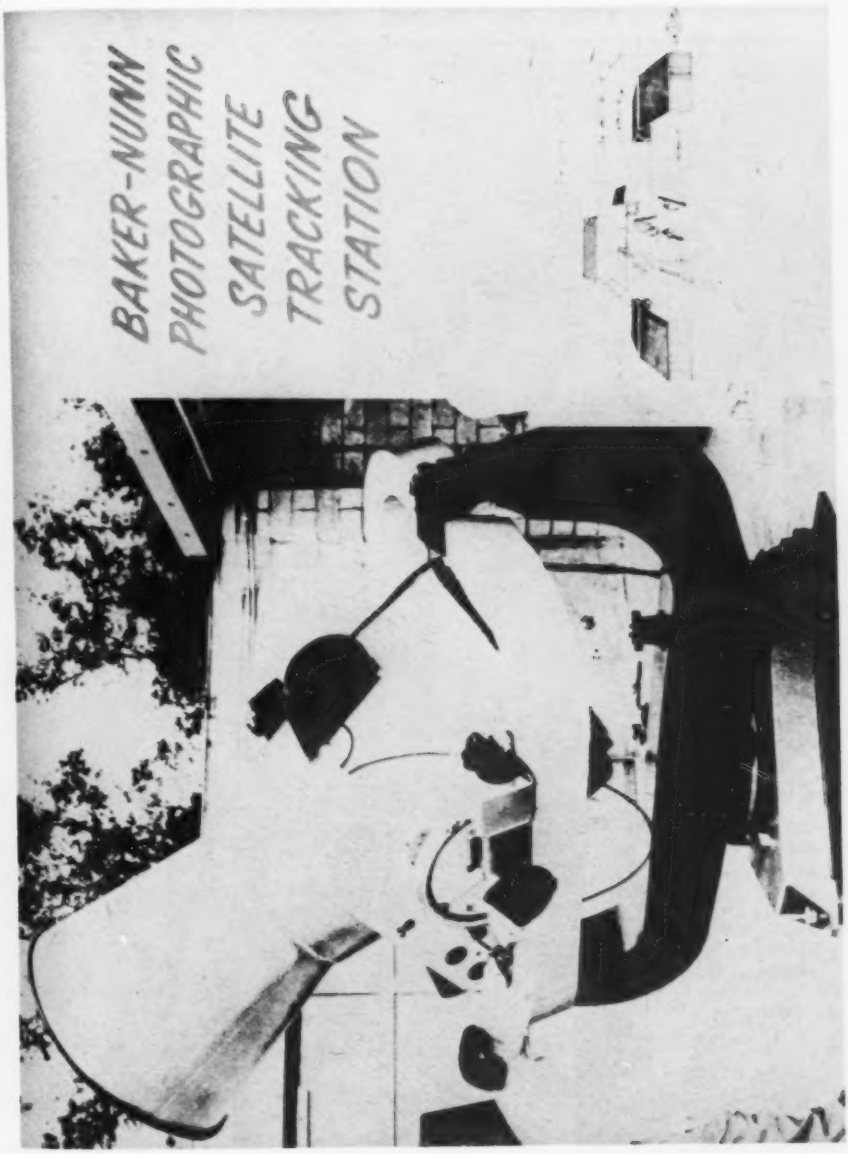
In addition, there are several existing tracking radars which will be used which are not shown on this map, but they are the ones which are now located at the Pacific missile range on the west coast, at White Sands Proving Grounds, at the Eglin Air Force Base, and at Canaveral. This particular orbit was chosen so that we would have very good tracking coverage during the critical reentry and landing portion of the flight so that we could insure recovery.

The last chart illustrates the type of equipment which will be installed at these stations. This is an FPS–16 tracking radar. Here again, this has a dish similar to the previous antennas, except it is much smaller. In this case we are measuring both the angles to the vehicle and also the distance or the range to the vehicle so that the orbit can be determined within a very short time.

That completes the presentation on tracking facilities. One other requirement is that the information which is picked up by both the data collecting equipment and the tracking facilities, to be of any usefulness must, of course, be transmitted back to the control center and the computing center in the United States, and Mr. John Mengel will discuss the communications facilities and the computing center required.

SUPPORT SYSTEMS
TRACKING AND DATA COLLECTING INSTRUMENTATION

ELEMENTS OF SPACE FLIGHT LAUNCH, CONTROL AND TRACKING NETWORK
5 CONTROL CENTER NETWORK CONTROL COMPUTING
2 TRACKING -ELECTRONIC OPTICAL
3 DATA COLLECTING
4 COMMUNICATIONS AND DATA TRANSMISSION
1 LAUNCHING AND INSERTION



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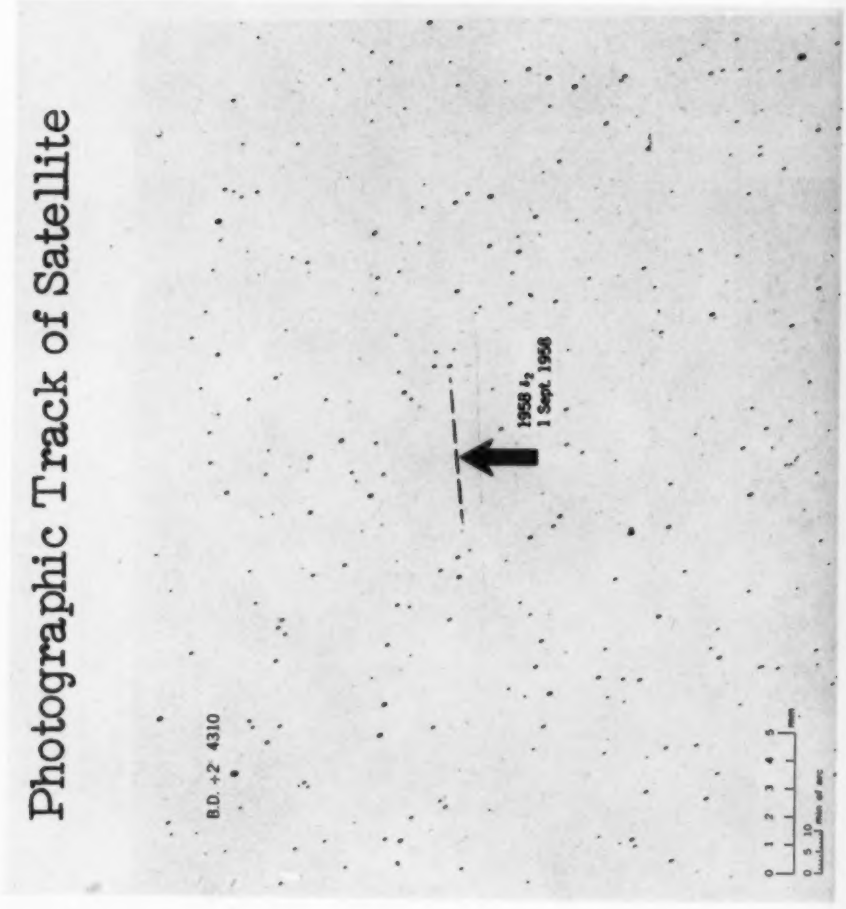
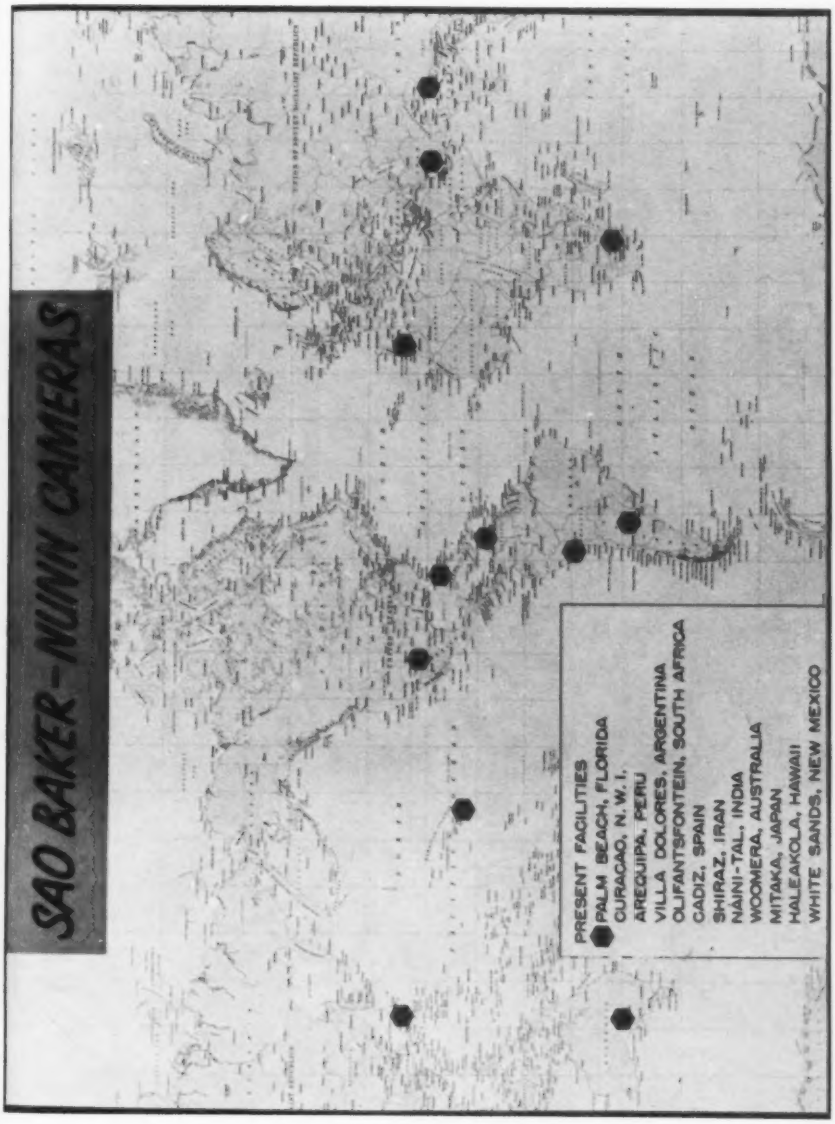
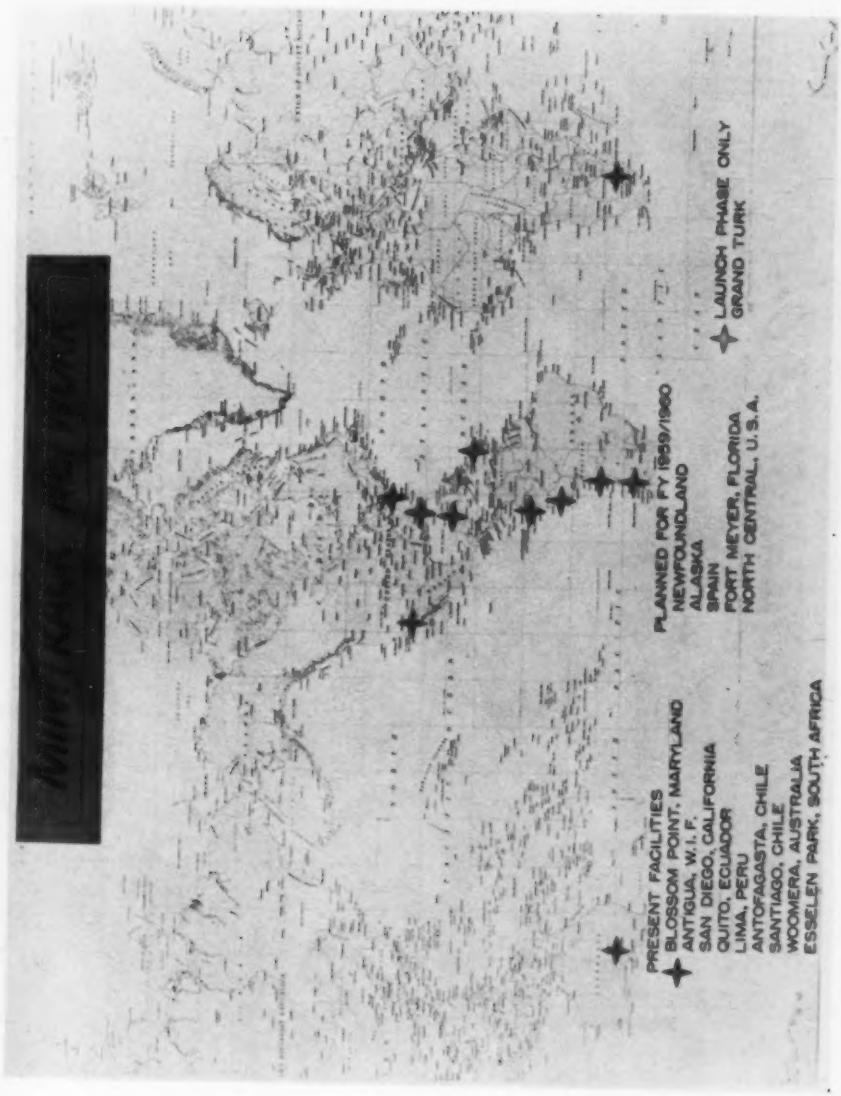
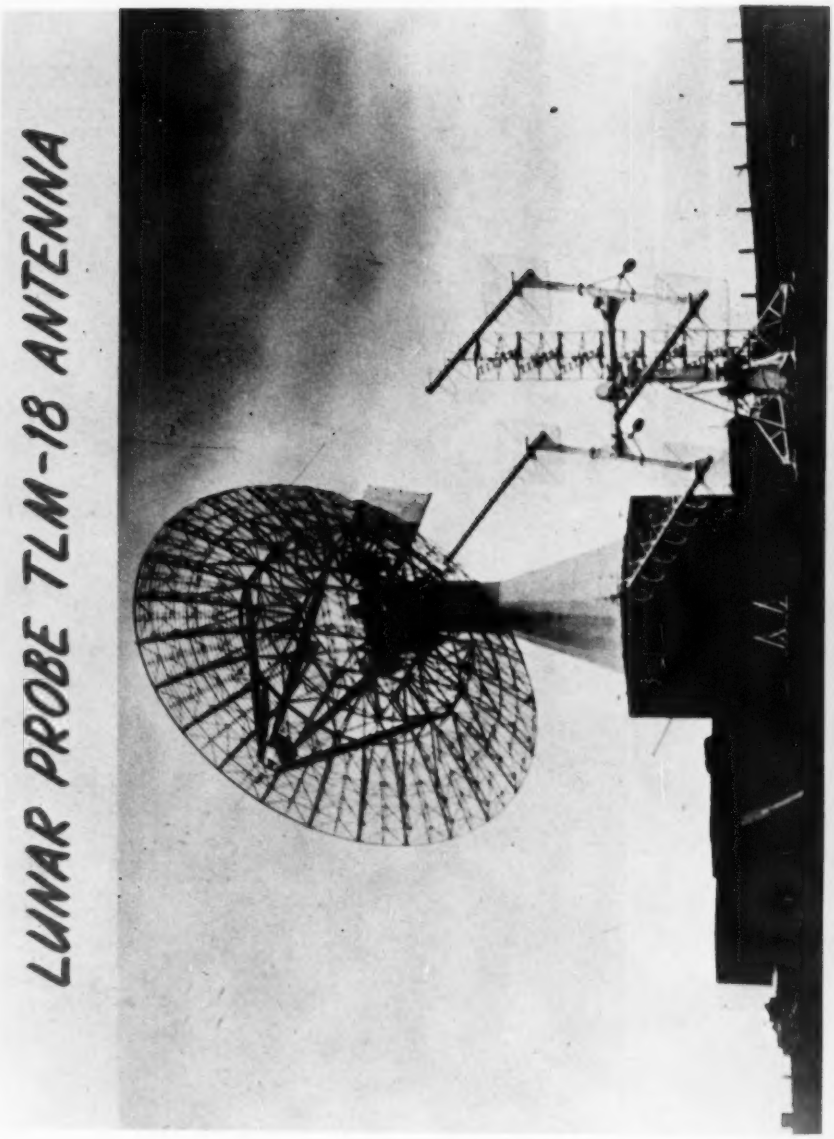
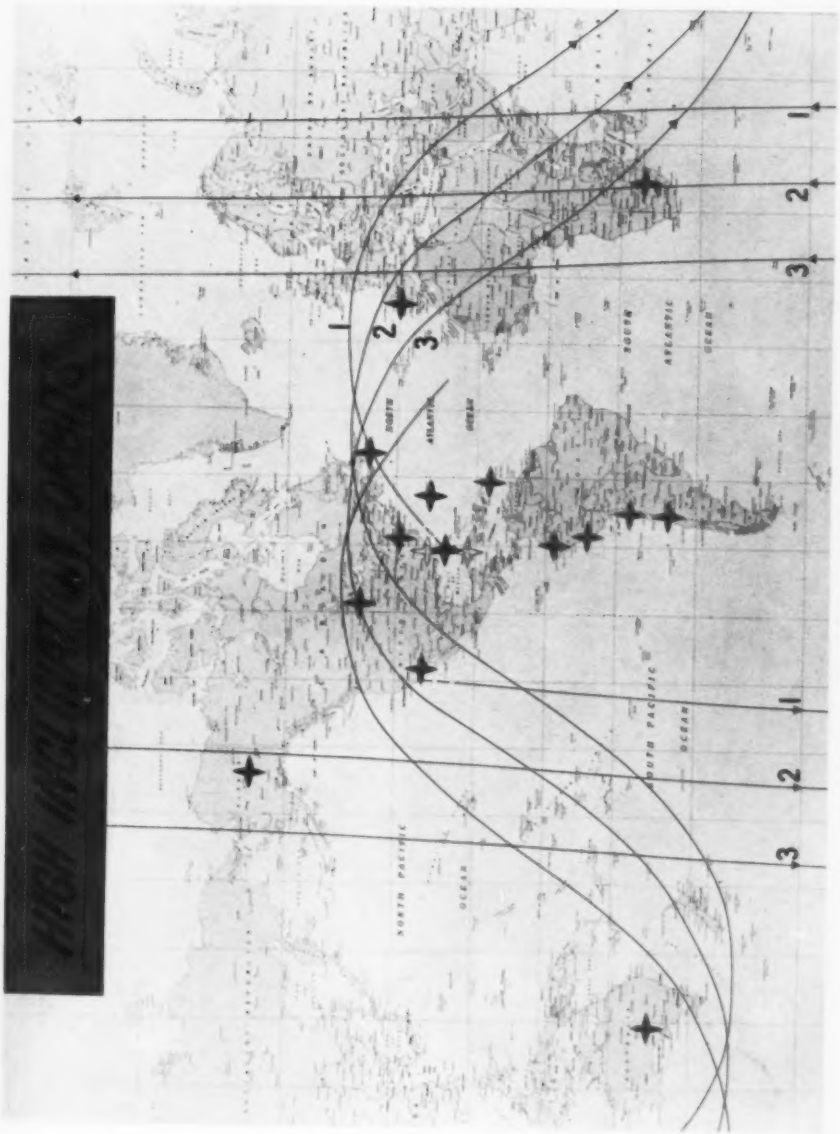

Photographic Track of Satellite
B.D. +2° 4310
1958 ι_2
1 Sept. 1958
0 1 2 3 4 5 mm
0 5 10 min of arc

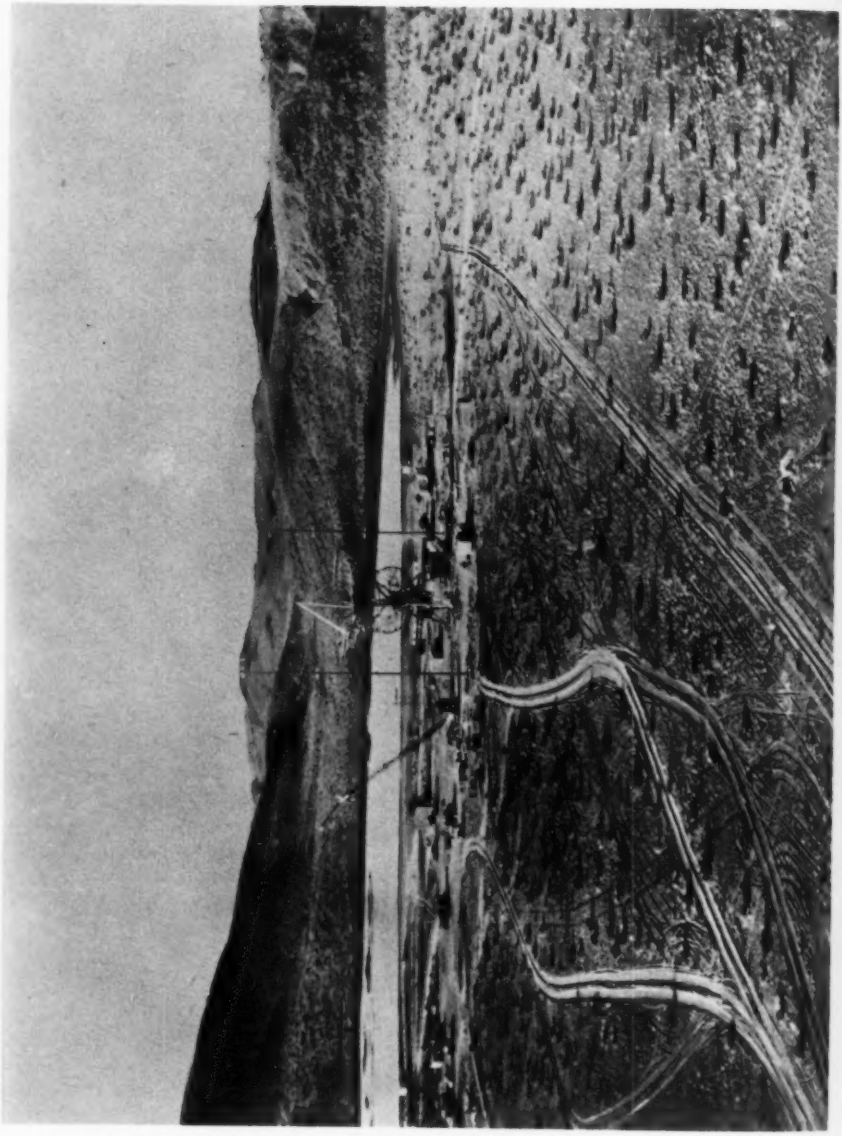

SAO BAKER-NUNN CAMERAS
PRESENT FACILITIES
PALM BEACH, FLORIDA
CURACAO, N. W. I.
AREQUIPA, PERU
VILLA DOLORES, ARGENTINA
OLIFANTSFONTEIN, SOUTH AFRICA
CADIZ, SPAIN
SHIRAZ, IRAN
NAINI-TAL, INDIA
WOOMERA, AUSTRALIA
MITAKA, JAPAN
HALEAKOLA, HAWAII
WHITE SANDS, NEW MEXICO

MINITRACK STATION


PRESENT FACILITIES
BLOSSOM POINT, MARYLAND
ANTIGUA, W.I.F.
SAN DIEGO, CALIFORNIA
QUITO, ECUADOR
LIMA, PERU
ANTOFAGASTA, CHILE
SANTIAGO, CHILE
WOOMERA, AUSTRALIA
ESSELEN PARK, SOUTH AFRICA
PLANNED FOR FY 1959/1960
NEWFOUNDLAND
ALASKA
SPAIN
FORT MEYER, FLORIDA
NORTH CENTRAL, U.S.A.
LAUNCH PHASE ONLY
GRAND TURK

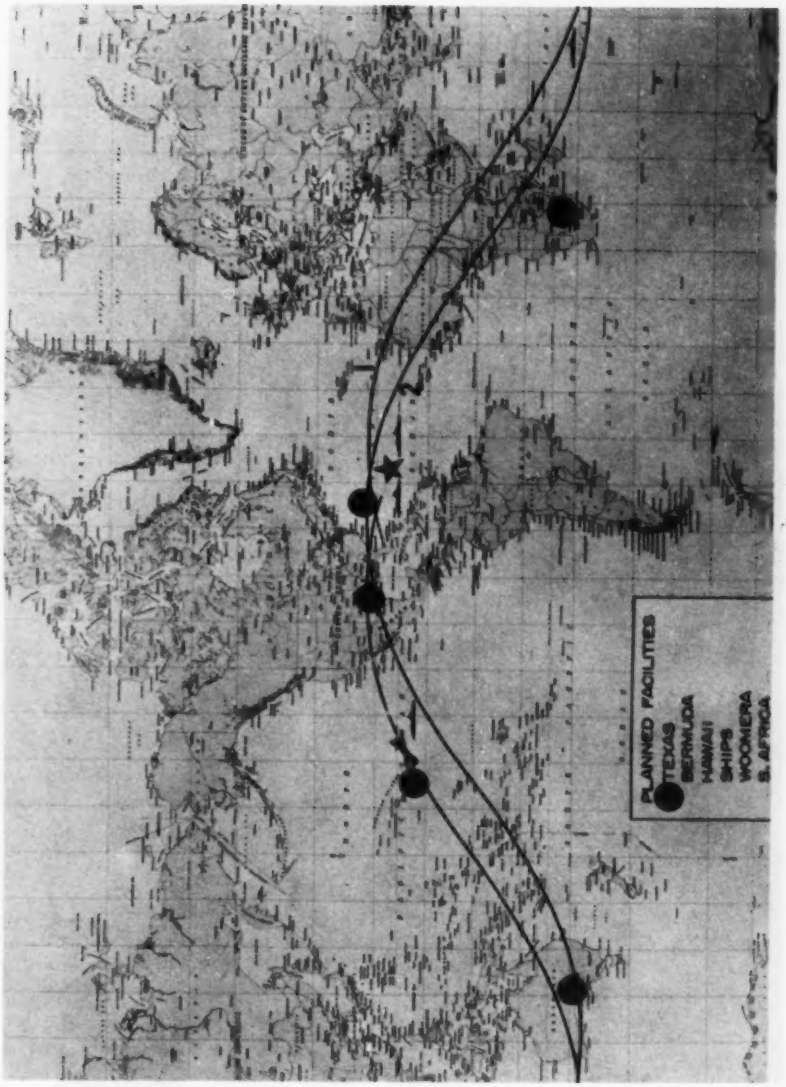

LUNAR PROBE TLM-18 ANTENNA


1
2
3
1
2
3
1
2
3
SOUTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN
NORTH PACIFIC OCEAN



DEEP SPACE COVERAGE
FROM THREE STATIONS
AUSTRALIA
SO. AFRICA
CALIFORNIA

MERCURY ORBITS



FPS-16 TRACKING RADAR

Senator STENNIS. All right. Thank you. Proceed, Mr. Mengel.

TESTIMONY OF JOHN T. MENGEL, HEAD, SPACE TRACKING SYSTEMS BRANCH, VANGUARD DIVISION, NASA

Mr. MENGEL. Referring back again to our initial chart here, you have now been taken through the launching, the tracking, and the data collecting. I would like to discuss the problems of communications and data transmission and the operations of the control center and the computing center itself.

The objective of a network obviously is to bring back the data. In our case we are interested in bringing back tracking data so that by computation we can determine the mathematical—determine mathematically the orbit itself and, in terms of flight data or telemetry data, obtain data in the form and quantity required by the scientists and engineers for whom the whole satellite or space vehicle program is being operated.

The nerve center of a network of this sort is the control center itself. This provides the administrative and technical control of the complete network operation, provides the point of contact with associated activities that either provide data into the network or require data from the network, and it provides the data and communications relay point for the network.

BASIC VANGUARD MINITRACK COMMUNICATIONS NETWORK

On this chart we have a typical communications network such as is required for global tracking networks of this sort. The example given here is the minitrack, the communications network associated with the minitrack tracking network. The reason for this is that this is not only typical, but it has been in operation since September of 1957. It has been used for every satellite and space vehicle that has been put in orbit by either us or the Russians, with two exceptions. That is the Pioneer series of space probes, which had a special frequency associated with them peculiar to the requirements of space; and the second is the Discoverer satellite series, which used a nonstandard frequency for tracking and for data acquisition.

As you can see on this chart, we utilize landlines, cables, teletype systems, and multichannel systems with these particular color codes. All of our data and all of our administrative and technical control are done by teletype. We have many auxiliary contact points, like the Army Map Service. This, incidentally, since that chart was started, has been discontinued. We go to the Vanguard Computing Center; we go to the Smithsonian Astrophysical Observatory; we go to the Jet Propulsion Laboratory and AGIWARN or Annee Geophysique Internationale Warning Agency, and things of that sort.

The minitrack network consists of Blossom Point, Md.; Fort Stewart, Ga.; two at Air Force Missile Test Center; four stations in South America-Quito, Lima, Antofagas, Santiago; a station in South Africa; a station in San Diego, Calif., and a station in Woomera, Australia. These are additional contact points.

It is an extensive communications network and it takes control at a control center to keep it.

TYPICAL NETWORK DATA FLOW CHART

In this network we have the following typical data flow chart. From all of our tracking stations—the minitrack, optical stations, military tracking groups, and university cooperating groups—we obtain many different types of raw tracking data. Our operations require them particularly in the forms of angles with free systems, frequencies, and ranges.

This data goes to the control center, where there is a data review, communications control, and from there it is sent immediately to the computing center. You will notice that the computing center is connected with their lines in the communications chart.

At the computing center the raw data is put into an IBM 704 electronic calculator, and it comes out as orbital data in the form of station predictions, Equator crossings, raw minitrack data, ephemerides —this is a fancy word for the timetable prediction of the satellites, for orbital elements and precision, definitive orbits of satellites that have gone by in the past.

Our user groups include our own tracking stations; we give them information as to when the next events will occur and where to look. These include the Smithsonian Astrophysical Observatory, which is responsible for the optical tracking stations. These need precise times, positions, and rates to enable them to direct their optical instruments at the satellite.

Similarly, we give information to military, to Government agencies, to worldwide observers, and to the universities, amateurs, commercial groups, right down to the press and radio and TV.

SATELLITE OPERATING PERIOD

This next chart is an aid to demonstrate what our present saturation capabilities are. This is a history of satellites which have been in the air up until about the 1st of February.

You notice it is not completed at the bottom here. The red period shows the time when the radio signals were on so we could perform radio tracking on the minitrack network. You will notice there were several periods when there were three satellites on at once; but the most important period at this point is the short period from the 15th to the 23d of May last year, at which time we had four satellites in orbit at once. At that time we were still in the period of completing our basic programs of what you might call closer to the research and development phase of the mathematical computation, but this period did demonstrate what the saturation capabilities were.

By putting people on overtime, both for communications and the control center and at the computing center, we were able to get through this period. As a result of that, we have changed our operational procedures, we have added some equipment to the network, and we are now putting in some automatic data-handling equipment. So that instead of these four, for the network as we now have it, to give out the data that we are now giving, we could probably take a dozen, or a few more than that, satellites all at once, all actively transmitting.

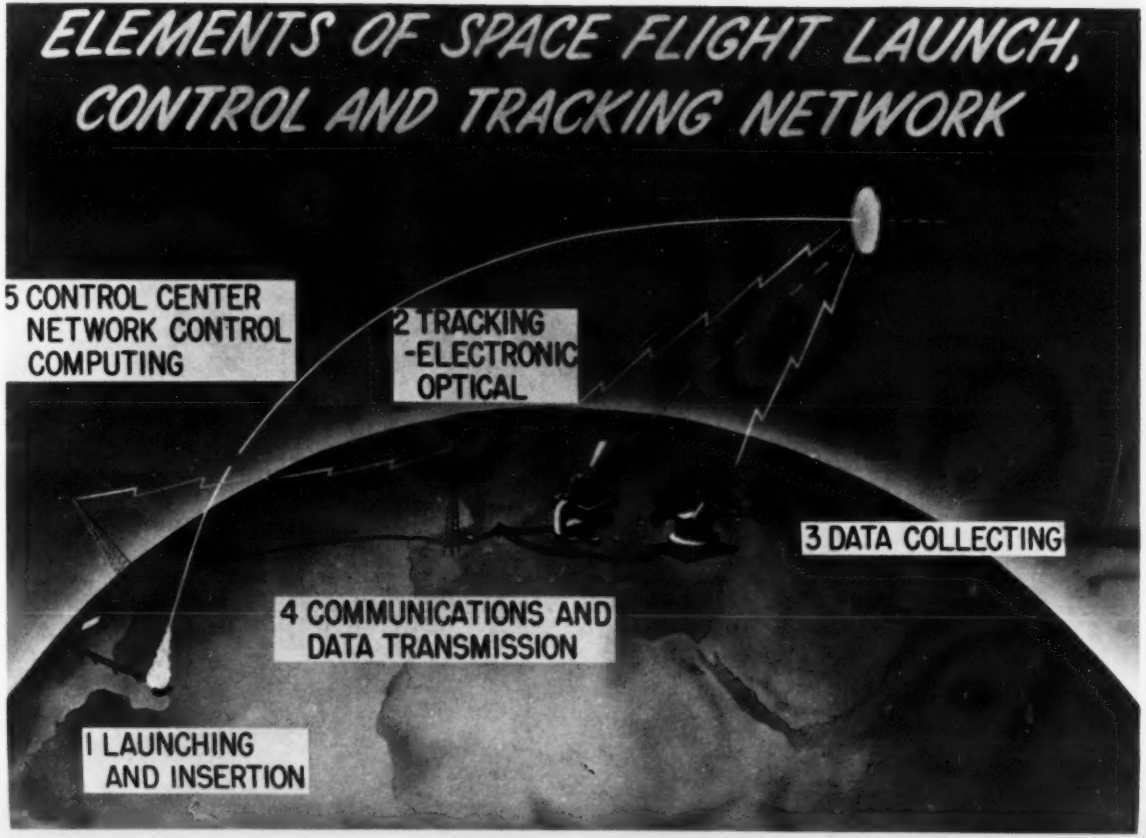
MINITRACK CONTROL AND COMPUTING FACILITIES

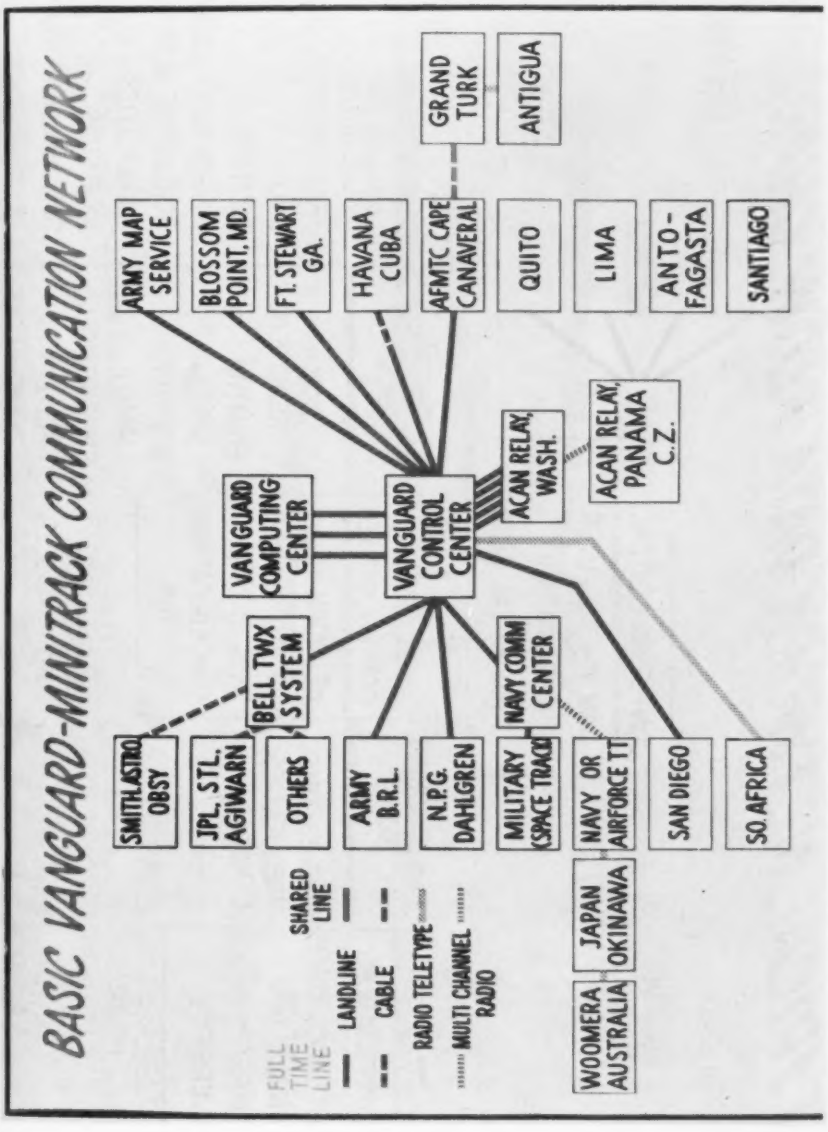
In order to give you an impression of the size and scope of these operations, there are two pictures here. This shows the communications room at the control center itself. This control center has 22 or 23 teletype machines at the present time. It handles on the order of 50,000 formal data messages a year. It has sent down over 6,000 formal messages a year. It has sent to the computing center over 6,000 formal data messages, and this puts it in the category of in the upper brackets of such communication relay centers in the country today.

The bottom picture is a view of the IBM 704 computer. I would point out at the present time these two units are located apart from each other. This [indicating] is on the grounds of the Naval Research Laboratory. The computing center itself is down in the 600 block of Pennsylvania Avenue. When we move to the Beltsville Space Center, these two will be combined in a single unit, which will make a considerable change for the better in the speed and efficiency of operations.

Thank you.

SUPPORT SYSTEMS
COMMUNICATIONS AND COMPUTING SYSTEMS


ELEMENTS OF SPACE FLIGHT LAUNCH, CONTROL AND TRACKING NETWORK
5 CONTROL CENTER NETWORK CONTROL COMPUTING
2 TRACKING -ELECTRONIC OPTICAL
3 DATA COLLECTING
4 COMMUNICATIONS AND DATA TRANSMISSION
1 LAUNCHING AND INSERTION



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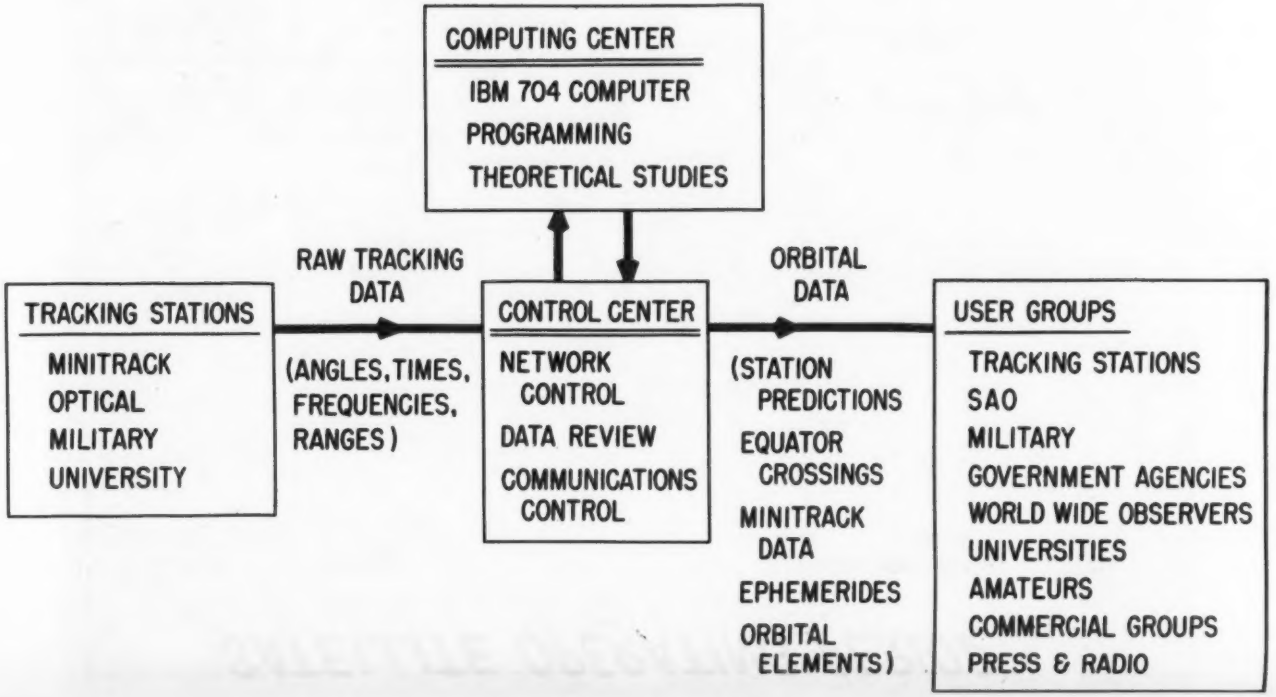
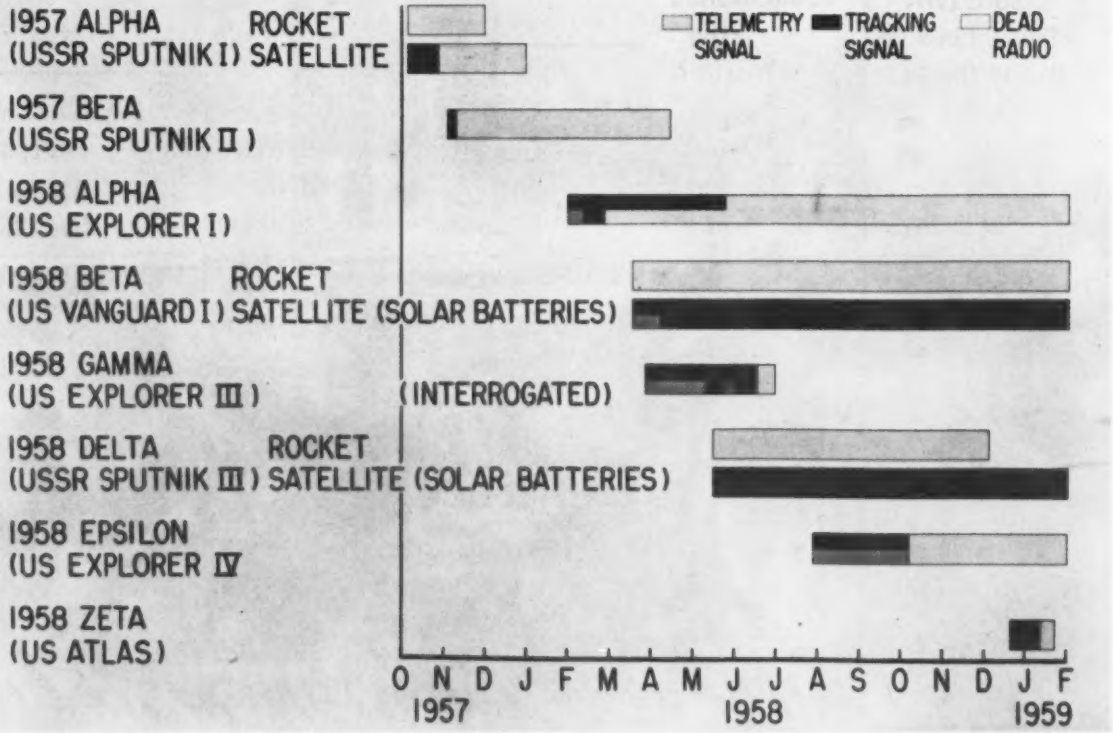
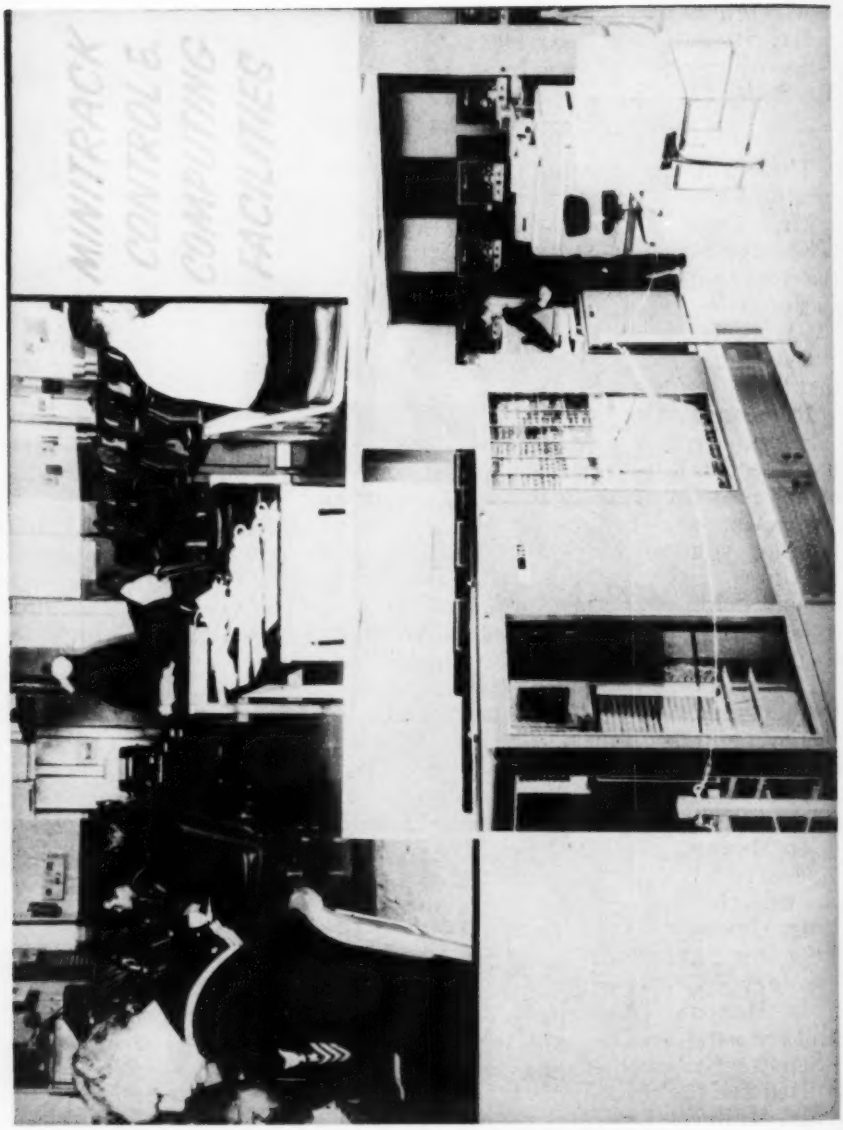
TYPICAL NETWORK DATA FLOW CHART



ELEMENTS) | PRESS & RADIO

SATELLITE OPERATING PERIOD




MINITRACK
CONTROLS
COMPUTING
FACILITIES

Senator STENNIS. Where did you say you were going to move to?

Mr. MENGEL. To the space center out at Beltsville on the grounds of the center there.

Senator STENNIS. Thank you.

All right, who is your next witness?

Mr. SMITH. That concludes our presentation, Mr. Chairman.

Senator STENNIS. May I just ask questions of one or two witnesses, Mr. Smith?

TRACKING STATIONS

These tracking stations you have been talking about here—the locations are in the authorization bill for this year; are they not?

Mr. SMITH. Yes.

Senator STENNIS. Are you well versed enough in the figures and the costs to indicate what it will cost to construct one of these tracking stations?

Mr. SMITH. Not in detail, sir.

Senator STENNIS. We will have other witnesses to take care of that?

Mr. SMITH. Yes, sir.

Senator STENNIS. Mr. Mengel, you said the tracking network you have been talking about was used some by the military. To what extent is it used, and does the Strategic Air Command use that?

Mr. MENGEL. Well, the Explorer series of satellites—I do not know whether you consider these military or nonmilitary—it was used for those. It is available to all operations in the research and development field that do not—well, to all operations which do not require security restrictions in our overseas stations, and to those which do operate at the frequencies for which these stations are set up.

I would point out that on the minitrack system, it is a fairly fixed frequency system. We have antennas which are peculiar to the frequency being used, and the installations are quite extensive, and it is not easy to change the frequency quickly.

Senator STENNIS. You do not use this in any way in connection with SAC's headquarters in Omaha, Nebr.?

Mr. MENGEL. No.

Senatro STENNIS. All right. Do you use it in any way in connection with the firing of a Nike missile?

Mr. MENGEL. No.

Senator STENNIS. It is entirely apart from that. So when you say "military," you mean largely military research and development?

Mr. MENGEL. When I referred to military here, I would refer to military satellite or space vehicle operations; yes, sir.

Senator STENNIS. Thank you. Is there any prospect of its being utilized for the actual operations of these military systems?

Mr. MENGEL. In some areas it would be suitable. Operationally, I do not know whether this is the best choice.

Senator STENNIS. What is concerning me is that we are having to build so many minitrack locations and all kinds of radar installations—just circling the globe—all of which seems to me to be very expensive, although I know it is necessary.

NASA TRACKING AGREEMENT WITH DEPARTMENT OF DEFENSE

Let me ask Mr. Smith a question now. You have an agreement that we have heard something about. I am not too familiar with it, but I thing you entered into it in January of this year—between the Department of Defense and the NASA—with reference to your global tracking facilities, the joint use of them——

Mr. SMITH. That is correct.

Senator STENNIS. For space flight, and so forth. How is that working out? Do you have a committee which operates it, or what? Is that within your category now?

Mr. SMITH. Yes, sir. We have an informal committee. We just got together with the people from the Advanced Research Projects Agency to compare notes, compare plans for tracking stations, and to see what we could work out from the point of view of joint use of the various tracking facilities. This agreement came as a result of that committee's work.

Senator STENNIS. Does anyone have the power of decision in connection with that agreement, or is it just something put together and not yet in operation?

Mr. SMITH. It is just barely getting into operation. We are now corresponding with the Advanced Research Projects Agency regarding the formal establishment of this committee and regarding the committee's responsibilities and authority.

Senator STENNIS. Well, could you give us something more definite on that before we close these hearings, either by coming back or giving it to us in writing, about the actual operation of it?

Mr. SMITH. This which I have just said——

Senator STENNIS. Who can make the decisions?

Mr. SMITH. What I have just said, I think, brings you up to the present time, and I do not have any further information.

Senator STENNIS. I thought if you could harden it up and give us something more definite before we took this bill before the Senate, it would be helpful.

Mr. SMITH. How long would it be?

Senator STENNIS. I would not put any timetable on it particularly, but it might be 2 or 3 weeks at the most.

Mr. SMITH. Certainly if we make any progress in the next 2 or 3 weeks, I would report back to you.

Senator STENNIS. I thought maybe you would try to make some progress and give us a report on it.

Mr. SMITH. All right.

(The following information was subsequently provided by NASA:)

The agreement between the National Aeronautics and Space Administration and the Department of Defense on global tracking, data acquisition, communications, and data centers for space flight, was signed January 10, 1959. A copy of this agreement is attached.

Paragraph No. 6 of this agreement provides for a Technical Committee with representatives from NASA and DOD to maintain a continuing study in monitoring of the global tracking, data acquisition, and communications problems, and periodically report their findings for action to the Secretary of Defense and the Administrator of National Aeronautics and Space Administration. Under this paragraph the Technical Committee has been established with a NASA membership of: Mr. Buckley, cochairman, Mr. Smith, and Mr. Mengel; and the Department of Defense membership of Mr. Price, cochairman, Mr. Gutheim, and Lieutenant Commander Holmes. The first meeting of this committee was held April 15, and the second is scheduled for May 7, 1959.

Although the launching of satellites to date has been so infrequent that schedule conflicts have not been a problem, the committee members recognize that these conditions would change with the dynamic and changing aspects of the Nation's space activities. At the present time, the committee members are working on the following:

(*a*) Scheduling criteria to prevent interference in the data collection at the all-important launch phase.

(*b*) Criteria of the use of radio frequencies to make broadest use of assignments without interference.

(*c*) Criteria as to the use of a specific facility, such as the Discoverer tracking equipment on Hawaii.

(*d*) Criteria to limit possible long time interference due to solar powered vehicle transmitters.

It will be the responsibility of the committee to make studies and recommendations on a continuing basis for the combined use and where possible integration of the tracking and data acquisition facilities for satellites and space vehicles.

It must be emphasized that in addition to the activities of this committee considerable and continuous daily informal contacts are being conducted between the personnel of NASA and DOD.

AGREEMENT BETWEEN NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AND DEPARTMENT OF DEFENSE ON GLOBAL TRACKING, DATA ACQUISITION, COMMUNICATIONS, AND DATA CENTERS FOR SPACE FLIGHT

1. The separate requirements of NASA and the Department of Defense for space tracking and data acquisition are recognized. The NASA requirements are primarily for research and development flights and the DOD requirements are primarily for research, operational flights and intelligence support.

2. Immediate and vigorous action is required in both agencies to implement the agreed on national program.

3. It is agreed that the following actions be started in the current year:

(*a*) Provide tracking and data acquisition stations for deep space probes at Woomera, Australia, and South Africa, using one of the existing 85-foot dishes. This will complete a three-station net including the existing NASA Goldstone facility for 24-hour coverage of deep space flights. These stations will be operated by NASA. High capacity data acquisition equipment will be required at these sites by the Department of Defense in the near future. These stations will provide for DOD requirements until the load increases so that parallel DOD equipment is required.

(*b*) Provide one of the existing 85-foot dishes in Spain and a secondary acquisition antenna with high capacity in Japan. These stations will be operated by the Department of Defense. These stations will provide for NASA requirements until the load increases so that parallel NASA equipment is required.

(*c*) Provide facilities required for Project Mercury, including those for injection, tracking, data acquisition, and reentry command. The NASA will provide and operate these facilities.

(*d*) Add four stations to the minitrack network and modernize remaining stations to provide coverage for polar flights. NASA will provide and operate these stations.

4. The need is recognized for two closely cooperating data reception and analysis centers, one operated by NASA as a continuation and expansion of the Vanguard center and one operated by the Department of Defense under space-track management at the Cambridge Research Center. These two centers will exchange data freely and provide mutual support for the national program.

5. The worldwide communications networks now in existence shall be shared equally by DOD and NASA.

6. A technical committee with representation from NASA and DOD shall maintain a continuing study and monitoring of the global tracking, data acquisition, and communications problems and periodically report their findings for action to the Secretary of Defense and the Administrator of NASA.

NEIL H. MCELROY,
Secretary of Defense.
T. KEITH GLENNAN,
Administrator, NASA.

WASHINGTON, D.C., *January 10, 1959.*

Senator STENNIS. I think that is rather important, because that is firming up and, you know, getting something working together.

Mr. SMITH. That is right. It prevents the NASA from duplicating a facility which might already be planned by the Department of Defense, and vice versa.

Senator STENNIS. In other words, it is a hard plan, it is something you can make an actual showing on.

Mr. SMITH. Yes, sir.

Senator STENNIS. I have asked several questions. Senator Cannon, do you have something further?

Senator CANNON. I have nothing further.

Senator STENNIS. Senator Martin, do you have something further?

Senator MARTIN. No.

Senator STENNIS. I have some that Mr. Lehrer has brought to my attention. Mr. Lehrer has a question to ask here.

EXPANSION AND IMPROVEMENT OF TRACKING FACILITIES REQUIRED

Mr. LEHRER. Mr. Mengel, you said that the present minitrack facilities with the change in the method of operation could now handle up to a dozen satellites. Does that include Russian satellites, or only U.S. satellites?

Mr. MENGEL. This would include Russian satellites, but not to the same extent, providing they stayed on frequencies for which we have modified stations; and, actually, for the Russian satellites we have not put out the same amount of data we do on American satellites. They are more direct users that require ephemerides and definitive orbits. So, if there are Russian satellites, we could take more of them, because they do not load up the computing center.

Mr. LEHRER. From the programs presented to this committee, it would appear it will not be long before we will be talking in the order of 25, 50, and 100 satellites in orbit. What does that mean in terms of your present facilities?

Mr. MENGEL. It means two things. It means initially a single computing machine probably would be overloaded and we would go into a second one.

Secondly, we would review the requirements for all satellites to make sure—for all satellite programs to make sure—they were not being given extra information that was not being used, and sort of put a gain control on the operations on this basis.

And, third, we are in the planning for improvement of the network, going into improved communications and improved data handling.

Mr. LEHRER. Is it fair to say, then, that the amount being asked in the 1960 budget for expansion and improvement of your tracking facilities is merely one installment of a continuing bill?

Mr. MENGEL. I would say that definitely this is the case, because you have to have the ground support to match the operation that you are planning.

Mr. LEHRER. That is all.

Senator STENNIS. On that very point, now—all of you say that you presented to us here a 10-year program in a broad sense, and of course I know you are not bound by that since you do not know what direction it will take.

ESTIMATED TOTAL COST OF REQUIRED TRACKING FACILITIES

But this money which is in the bill for authorization, after all, is just the initial step and just the initial requirement for this program—what would you say is the total cost, or would you put one on it?

Mr. SMITH. For the tracking facilities, sir, I think——

Senator STENNIS. I was referring to the tracking facilities.

Mr. SMITH. Yes, sir. In discussing this with the Advanced Research Projects Agency and the Department of Defense, we estimated, I believe the number was $50 to $75 million a year for the next few years. This is for NASA and the Department of Defense, and I believe——

Mr. MENGEL. For the research and development phase.

Mr. SMITH. It included construction, too, did it not?

Mr. MENGEL. Not for nonmilitary operation.

Mr. SMITH. It included, for tracking, the research and development phases of the program.

Senator STENNIS. Your major installations will have to come later?

Mr. SMITH. Pardon?

Senator STENNIS. Your major installations, then, would have to come later, is that right?

Mr. SMITH. What is being referred to is the fact that for some of the advanced programs, the military programs in particular, which are classified——

Senator STENNIS. Yes.

Mr. SMITH. Will get so involved and will require facilities which will be beyond the type we are using for research and development, that it would reach the point where the research and development facilities could not handle the day-to-day, routine operations of the sort of satellites which are being planned by the military.

Senator STENNIS. I am not trying to trap you, and I would not want you to be held to any figure, of course, but we ought to have some idea about how much the downpayment is, and then how much the installments are going to be. We do not want to be asked a question, "Well, can you give us some idea about the magnitude of this program?" and have to say no—we have got to have some idea.

But you are still in the research and development stage here, so far as your figures are concerned.

Mr. SMITH. Yes, indeed, very much in the research and development stage.

Senator STENNIS. That gets us by one barrier.

Dr. Hagen, is there anything you might want to say? You indicated you might want to say something there.

Dr. HAGEN. One thing I did want to put in was that your question is very difficult to answer because it is highly dependent on the success of the various planned satellite programs and the large number of data channels that each is going to have, so that one can only plan in a very general way as to what the needs will be a year or 5 years from now.

Senator STENNIS. I do not think you ought to try to put a firm figure on it at all—I was not suggesting that you do. Is there anything else now that any of you wish to say before we conclude these hearings?

Yes, Mr. Lehrer.

Mr. LEHRER. I would like to clear one thing for the record. In discussing the agreement between the Department of Defense and NASA, you mentioned that there had been informal discussions at a technical level with regard to the location of stations.

FIXING RESPONSIBILITIES FOR TRACKING FREQUENCIES

Has anything been done at the technical level to fix responsibility to assure that there will be uniform frequencies, uniform specifications, and so forth, so that we can be sure that the man in space, for example, can safely communicate with all tracking stations?

Mr. SMITH. Yes, sir. These problems were discussed in a general sort of way at the same time that we discussed station locations. The problem of frequencies, for instance, is a tremendous one, and one which has not been completely solved. It is being worked on, and it will have to be coordinated and will be coordinated with the Department of Defense.

Mr. LEHRER. Are field agencies being consulted on this? For example, have the people at the Atlantic Missile Range been brought into these discussions?

Mr. SMITH. The people at the Atlantic Missile Range were not a part of the original informal committee. They are a part of the Department of Defense, of course, and I assume that through their channels they are aware of what the Department of Defense is doing.

Mr. LEHRER. Do you know whether they are aware of it, or do you merely surmise they should be aware of it?

Mr. SMITH. I merely surmise that they should be.

Mr. LEHRER. Thank you.

Senator STENNIS. We have had some kind of reports here about a conflict in the use of the tracking stations at the time of Pioneer IV and Discoverer I. Did you have any conflict on that or any trouble points? Can anyone answer that question?

Dr. HAGEN. I would answer for Discoverer I, there could not be a conflict because we were not alerted as to the frequencies used, and it was not compatible with the frequencies for which the minitrack was designed.

Mr. MENGEL. Could I make one comment on these frequencies. When you made this comment about the Atlantic Missile Range, the basic frequencies we are using have been coordinated between the Department of Defense and NASA through this interdepartmental radio committee actually. In the DOD all of the users, the people who are interested in this, have been contacted, and before these frequencies have gone to that committee for approval, I understand that they had everybody's approval, including the test ranges, so the requirement as expressed in the Interdepartment Radio Advisory Committee itself was agreed to by NASA as a coordinated frequency request.

Senator STENNIS. Do I understand now that you always clear these things, inform each other about these firings, so that there will be no conflict there? How does that work?

Mr. MENGEL. In the research and development phase, in the research and development firings, I think this is the case. I think that the exception we mentioned here was considered in another category that had its own tracking capability, and they did not use the one we are talking about here.

Senator STENNIS. This geodetic satellite, now, you may not want to go into this any further in open session, but will that help you get more accurate information with reference to points anywhere in the world that you——

Dr. HAGEN. Could you put that question the other way around a little bit?

Senator STENNIS. Yes. All right.

Dr. HAGEN. During the operations, especially with Vanguard I, we have measured the orbit, tracked it with a minitrack system, determined its orbit, and then these computations were made available to the Army Map Service, which has operated in a beginning way tracking stations on islands specifically to measure geodetic parameters from the known orbit of the satellite; so we have been cooperating in that way.

Senator STENNIS. All right. Thank you. We certainly thank you gentlemen very much. I think this is a very worthwhile contribution you have made. We look forward to getting all of this in the record. at its proper place, and presenting it to the Congress.

We will recess until 10:30 tomorrow.

(Whereupon, at 5:10 p.m., the subcommittee recessed, to reconvene at 10:30 a.m., Thurday, April 9, 1959.)

NASA AUTHORIZATION FOR FISCAL YEAR 1960

THURSDAY, APRIL 9, 1959

U.S. SENATE,
NASA AUTHORIZATION SUBCOMMITTEE
OF THE COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10:45 a.m., in room 224, Old Senate Office Building, Senator John Stennis presiding.

Present: Senators Stennis, Smith, and Martin.

Also present: Kenneth E. BeLieu, staff director; Max Lehrer, assistant staff director; Dr. Glen P. Wilson, chief clerk, and Dr. Earl W. Lindveit, assistant chief clerk.

Senator STENNIS. The meeting will come to order, please.

I have a very short statement. We will continue our hearings this morning on the authorization request for fiscal year 1960 for the National Aeronautics and Space Administration.

These hearings have been divided into two major phases. The first phase, which was started on Tuesday, is designed to obtain a comprehensive presentation of the technical and scientific aspects of all the important projects involved in the space program. This is being done so that the American people will be given a complete picture of our planning for the space program for the next decade. In short, the product of this first phase of our hearings will constitute a primer of the space program which should be of considerable interest and usefulness, not only to the members of this committee and to the Congress, but to students and the American people generally.

As outlined by the Chair at the outset of these hearings, after the completion of the first phase of the hearings, which will cover the picture as our scientists see it for the next 10 years, the committee will proceed with the second phase, which will involve a detailed examination of the specific programs and amounts proposed for fiscal year 1960.

So far, we have heard presentations covering the general subjects of advanced technology in the propulsion area, atmospheres research, space vehicle applications, and the facilities and systems supporting space vehicles.

This morning we will cover the general subject of manned space flight. Following this there will be presentations on advanced technology and aircraft.

Today's schedule has been arranged so that all unclassified material will be covered first in open session. Later this afternoon, it will be necessary to hold an executive session to consider certain classified items.

As previously announced, NASA has been requested to review the transcript of the classified hearings and to delete only those matters which cannot be disclosed without adverse effect on our national security. The sanitized testimony will then be made public as quickly as possible. In this way we will be able to assure that the American people are given the maximum possible information about these important space programs.

Our first witness this morning will be Mr. George M. Low, chief of the manned space flight program of NASA.

Mr. Low and the others who expect to testify this morning, will you please stand and be administered the oath as a group. I will call your names. Mr. Low, Mr. Faget, Mr. Mathews, Brigadier General Flickinger, Dr. Worf, Mr. Clayborne, Dr. Chapman, Mr. Ault, and Mr. Heldenfels. Mr. Cortright, Mr. Milwitzky, and Mr. Jaffe have already been sworn. The remaining witnesses will be sworn later in the day before they give their testimony.

Do you and each of you gentlemen swear that your testimony in this hearing will be the truth, the whole truth, and nothing but the truth, so help you God?

Mr. LOW. I do.

Mr. FAGET. I do.

Mr. MATHEWS. I do.

General FLICKINGER. I do.

Dr. WORF. I do.

Mr. CLAYBORNE. I do.

Dr. CHAPMAN. I do.

Mr. AULT. I do.

Mr. HELDENFELS. I do.

(The biographical sketches of the witnesses follow:)

GEORGE M. LOW, CHIEF, MANNED SPACE FLIGHT PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

George M. (Michael) Low was appointed chief of the manned space flight program in the Office of the Assistant Director for Advanced Technology when the National Aeronautics and Space Administration was established on October 1, 1958. Currently he is coordinating the manned satellite program, Project Mercury. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1949.

Low is a native of Vienna, Austria. He came to the United States as a boy in 1940, and became a naturalized citizen 5 years later. He earned a bachelor of science degree in aeronautical engineering from Rensselaer Polytechnic Institute in 1948.

Low joined the NACA in 1949 as an aeronautical research scientist at the Lewis Flight Propulsion Laboratory, Cleveland, Ohio. During his years at the Lewis facility, he was head of the Fluid Mechanics Section and later Chief of the Special Projects Branch. He specialized in research in the fields of aerodynamic heating; boundary layer theory and transition; and internal airflow in supersonic and hypersonic aircraft.

The author of numerous technical papers and articles, Low is an associate fellow of the Institute of the Aeronautical Sciences, and a member of the American Rocket Society.

Mr. and Mrs. Low (the former Mary McNamara) and their four children live at 11102 Dewey Road, Kensington, Md.

MAXIME A. FAGET, CHIEF, FLIGHT SYSTEMS DIVISION, SPACE TASK GROUP, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Maxime A. Faget, Chief of the Flight Systems Division of the National Aeronautics and Space Administration's Space Task Group, has contributed many of the original design concepts embodied in the Project Mercury manned satellite vehicle.

Before his appointment to his present position, on November 5, 1958, he conducted research on the blunted leading face concept as head of the Performance Aerodynamics Branch of the Pilotless Aircraft Research Division, Langley Aeronautical Laboratory, National Advisory Committee for Aeronautics.

Faget was born in British Honduras, the son of a surgeon in the Public Health Service. He earned a bachelor of science degree in mechanical engineering from Louisiana State University in 1942.

After 3 years as an officer in the U.S. Navy, Faget joined the NACA in 1946 as a research scientist at the Langley Laboratory. He is an authority in a number of aerodynamic fields, including rocketry, bomb ejection at high speeds, missile reentry theory, heat transfer, and aircraft performance. He is the author of a number of technical papers and has served on special working groups dealing with Navy missile projects and atmospheric reentry bodies.

Faget is a member of the Institute of the Aeronautical Sciences, the American Rocket Society, and the Academy of Model Aeronautics.

Mr. and Mrs. Faget and their three children live at Newport News, Va.

CHARLES W. MATHEWS, CHIEF, OPERATIONS DIVISION, SPACE TASK GROUP, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Charles W. Mathews was appointed Chief of the NASA Space Task Group Operations Division on November 5, 1958, after 16 years as a scientist in the Flight Research Division of the Langley Aeronautical Laboratory, National Advisory Committee for Aeronautics, the predecessor of the National Aeronautics and Space Administration.

Mathews is responsible for the operational phases of the manned satellite program, called Project Mercury. He is responsible for launch and recovery of the manned satellite, planning and implementing the worldwide tracking and communications network, coordinating research and development test and buildup flights of the capsule, determining the training and conditioning programs for capsule pilots, and compiling the detailed operations plans for each flight.

A native of Duluth, Minn., Mathews is a graduate of Rensselaer Polytechnic Institute. He is the author of numerous technical papers, and is a member of the Institute of the Aeronautical Sciences.

Mr. and Mrs. Mathews and their two children live in Yorktown, Va.

BRIG. GEN. DON D. FLICKINGER, STAFF SURGEON AND DIRECTOR OF LIFE SCIENCES, HEADQUARTERS, AIR RESEARCH AND DEVELOPMENT COMMAND, DEPARTMENT OF THE AIR FORCE

Don Davis Flickinger was born in Erie, Pa., on November 26, 1907. He was graduated from Los Angeles High School in 1925 and from Stanford University, Calif., in 1929. Four years later he received his master's degree from Stanford Medical School, also taking postgraduate training at Vanderbilt School of Medicine and Harvard School of Medicine.

Upon entering the Air Force in 1937, General Flickinger was sent to the School of Aviation Medicine at Randolph Field, Tex., for training as a flight surgeon.

Going to March Field, Calif., in November 1937 as flight surgeon to the 19th Bomb Group, upon being reassigned to the 17th Attack Group, he began his field investigations of the aeromedical problems in operational Air Force units.

Ordered to Wheeler Field, T.H., in January 1940 as flight surgeon to the 6th Pursuit Group, General Flickinger was medical officer of the day on December 7, 1941, when the Japanese attacked. Prior to this in September 1941 he had been selected to accompany the 14th Provisional Squadron of nine B–17's on the first trans-Pacific flight from Hawaii to the Philippines.

Assigned as flight surgeon of the 7th Fighter Command until October 1942, General Flickinger was then ordered to the China-Burma-India Theater as flight surgeon for the Air Transport Wing flying the "Hump."

In June 1944 he returned to the United States and became Chief of the Aeromedical School at the Air Force School of Applied Tactics, Orlando, Fla., and in 1947 became director of research at the School of Aviation Medicine.

Becoming air surgeon at Headquarters, 8th Air Force, Carswell Air Force Base in 1949, General Flickinger held this position until November 26, 1951, when he was assigned to the Air Research and Development Command as the first director of human factors at that command. In this capacity he was responsible for research and development in the human factors area dealing with the biologic, psychologic, and sociologic sciences.

Upon the reorganization of the Air Research and Development Command in February 1954, General Flickinger was given the dual assignment of director of research and assistant director for technical operations.

After serving in this capacity for several months he was appointed director of research. As director of research, General Flickinger directed a continuing research effort in the areas of mechanics, chemistry, mathematics, physics, propulsion, and solid state sciences. He also directed supporting research and development programs in the areas of geophysics and human factors. In August of 1955 when the Office of Scientific Research was set up as a separate activity to increase emphasis on basic research and to provide closer liaison with other research organizations and renamed the Air Force Office of Scientific Research, General Flickinger became the first commander.

In October 1955, General Flickinger was reassigned as commander of the Air Research and Development Command's European office in Brussels, Belgium, and on June 15, 1957, returned to the United States for duty as staff surgeon and director of human factors, ARDC Headquarters, Baltimore, Md.

The Don Flickinger trophy, awarded by Air Rescue Service for the best pararescue team, is named in honor of General Flickinger for having been one of the first medical doctors to parachute to a rescue.

His decorations include the Legion of Merit with one oak leaf cluster, Distinguished Flying Cross, Bronze Star, Soldiers Medal, and the Air Medal. He is rated a flight surgeon.

General Flickinger and his wife, Polly T., have two children, Daphne A., and Don D.

PROMOTIONS

Commissioned a first lieutenant (permanent) December 1, 1934; he was promoted to captain (permanent) June 24, 1937; to major (temporary) January 4, 1942; to lieutenant colonel (temporary) November 24, 1942; to colonel (temporary) September 7, 1943; to major (permanent) August 20, 1947; to lieutenant colonel (permanent) August 10, 1948; to colonel (permanent) July 27, 1950; to brigadier general (temporary) October 27, 1954.

DOUGLAS L. WORF, CHIEF, BIOLOGY AND LIFE SUPPORT SYSTEMS PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Douglas L. (Lowell) Worf joined the headquarters staff of the National Aeronuatics and Space Administration as Chief of the biology and life support systems program on November 10, 1958. Previously he was engaged in health physics at the U.S. Atomic Energy Commission.

Dr. Worf is a native of North Dakota. He earned a bachelor of science degree in chemical engineering from the University of Toledo in 1938. In 1952 he was awarded a Ph. D. in chemistry (major in biology) from Georgetown University.

After 2 years as an officer in the U.S. Navy, Dr. Worf joined the staff of the Office of Naval Research as a biophysicist in 1946. From 1952 until his appointment to the NASA staff he was a scientist at the Atomic Energy Commission, first as a biophysicist in the Biology and Medicine Division, and later in Health Physics, Reactor Development Division.

Dr. Worf has performed research in biophysics, radio biology, molecular biology, and physiological stress (temperatures, shock syndrone, radiation syndrone). He represented the IGY-National Academy of Science Committee on Cosmic Radiation during 1955–56. He is a member of the American Nuclear

Society, the American Chemical Society, the American Meteorological Society, and the Washington Philosophical Society.

Dr. and Mrs. Worf (the former Patricia Pierce) and their three children live at 4542 North 40th Street, Arlington, Va.

JOHN P. CLAYBORNE, TECHNICAL ASSISTANT TO THE DIRECTOR, GUIDANCE AND CONTROL LABORATORY, ARMY BALLISTIC MISSILE AGENCY, HUNTSVILLE, ALA.

John P. Clayborne has been technical assistant to the Director of the Guidance and Control Laboratory, Army Ballistic Missile Agency, Huntsvile, Ala., since 1957.

A native of Minnesota, Clayborne earned a bachelor of science degree in meteorology from New York University in 1943. After 3 years in the U.S. Army Air Corps, he joined Western Electric as a design engineer in 1946. In 1949 he joined the firm of J. A. Maurer, Long Island City, N.Y., and was engaged in the development of special photographic equipment for the military services.

From 1950 to 1957, Clayborne was concerned with torpedo countermeasures work at the U.S. Navy Mine Defense Laboratory, Panama City, Fla. He eventually became acting head of the Torpedo Countermeasures Division.

During his career, Clayborne has specialized in research in underwater acoustics and hydrodynamics, electricity and magnetism, and missile guidance. He is a member of the America Rocket Society and the Society of Motion Picture and Television Engineers.

Mr. and Mrs. Clayborne (the former Kathyrn Butt) and their two children live at 1502 Elmwood Drive, Huntsville, Ala.

DEAN R. CHAPMAN, RESEARCH SCIENTIST, HIGH-SPEED RESEARCH DIVISION, AMES RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dean R. Chapman, research scientist at the NASA's Ames Research Center, Moffett Field, Calif., is widely known for his research on entry into planetary atmospheres. He has also worked on flow separation at supersonic speeds and the effects of trailing edge bluntness on drag and lift. Dr. Chapman has been associated with the Ames facility since 1944.

Born at Fort Sumner, N. Mex., in 1922, Dr. Chapman received bachelor, master, and doctoral degrees from California Institute of Technology in 1944 and 1948.

Dr. Chapman began his career at Ames as an aeronautical engineer. From 1946 to 1948 he was at CalTech as a National Research Council predoctoral fellow, returning to Ames when he received his Ph.D.

Dr. Chapman received the Lawrence Sperry Award of the Institute of the Aeronautical Sciences for 1952, for "contributions to the basic knowledge of skin friction, base pressure and heat transfer at supersonic speeds." The Sperry Award is given annually for a notable contribtuion made by a young man to the advancement of aeronautics. He will receive the Rockefeller Public Service Award on April 14, 1959, as an outstanding career civilian in the Federal Government. The award will enable him to study space mechanics at Cambridge University in England next year.

The author of a number of technical papers, Dr. Chapman is a member of the Institute of the Aeronautical Sciences, Sigma Xi, and Tau Beta Pi.

Dr. and Mrs. Chapman and their two children live at 251 Whitclam Court, Palo, Alto, Calif.

G. MERVIN AULT, ASSISTANT CHIEF, MATERIALS AND STRUCTURES RESEARCH DIVISION, LEWIS RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

G. Mervin Ault was appointed Assistant Chief of the Materials and Structures Division of the NASA's Lewis Research Center, Cleveland, Ohio, in 1958. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1943 at the Lewis facility.

Born in Pomeroy, Iowa, in 1921, Ault was awarded a bachelor of science degree in engineering by Iowa State College in 1943.

Ault joined the staff at Lewis as an aeronautical research scientist in the Lubrication and Wear Research Section. In 1944 he was transferred to the

Materials Research Section. In 1946 he was named Assistant Head of the Section, and in 1950 was appointed Head.

Ault was appointed Chief of the Materials Research Branch in 1954, and in 1958 was named to his present position.

During his career at the Lewis Research Center, Ault has been primarily engaged in high-temperature materials research. He has also worked in the field of jetengine reliability.

Ault is the author of numerous technical reports and articles for technical journals. He is a member of the American Institute of Mining Metallurgical, and Petroleum Engineers; and the American Society for Metals.

Mr. and Mrs. Ault (the former Virginia White) and their two children live at 25920 Myrtle Avenue, Olmstead Falls, Ohio.

RICHARD R. HELDENFELS, CHIEF, STRUCTURES RESEARCH DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Richard R. Heldenfels is Chief of the Structures Research Division at the NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA at the Langley facility in 1947.

Born in Beeville, Tex., in 1920, Heldenfels earned a bachelor of science degree in aeronautical engineering from Massachusetts Institute of Technology in 1942. He served as an officer in the U.S. Army Air Force from 1942 to early 1947.

He worked for a few months with Curtiss-Wright, Columbus, Ohio, and then joined the staff at Langley as a junior aeronautical engineer in the Structures Research Division.

In 1952 Heldenfels was assigned to the Office of the Chief of Research at Langley, and in 1955 he was appointed head of the Aerothermal Branch of the Structures Research Division. He was named Chief of that Division in 1956.

He is a member of the Institute of the Aeronautical Sciences, the American Rocket Society, the American Astronautical Society, and the Engineers Club of the Virginia Peninsula.

Mr. and Mrs. Heldenfels and their two children live at 17 Goodwin Road, Warwick, Va.

Senator STENNIS. Mr. Low, please come to the table.

I understand that the names of the seven men chosen for Project Mercury will be made public at 2 o'clock this afternoon; is that correct?

Mr. LOW. That is correct.

Senator STENNIS. Well, I have been wanting to get to the stage in this hearing where I could ask you about these astronauts. I did not know whether it was wise to announce those names yet—I am not going to ask you their names. You will handle that in your own way later. But what about these gentlemen? Have you taken them from the services?

Mr. LOW. They are all graduates of military test pilots' schools, and they are all in the services.

Senator STENNIS. They are all in the services?

Mr. LOW. Yes, sir.

Senator STENNIS. Do you have different services represented? I imagine you do.

Mr. LOW. Yes. We have men from the Air Force, from the Navy, and the Marine Corps.

Senator STENNIS. So among the seven that are represented, you have these three services represented?

Mr. LOW. We had, as you know, some fairly high qualifications for these men that will be discussed later on this morning.

Senator STENNIS. All right.

Mr. LOW. And these qualifications in particular required that the men were qualified, experienced jet test pilots, and therefore

the only two of the services could contribute to the group. Unfortunately, there were no men in the U.S. Army that could enter into it.

Senator STENNIS. How many do you have from the Air Force, the Navy, and the Marine Corps, if that is a fair question?

Mr. LOW. I believe there will be three from the Air Force, three from the Navy, and one from the Marine Corps, a total of seven.

Senator STENNIS. Will these men—well, you can take that up when you get to it. You say you will bring it out.

All right, you proceed in your regular way, Mr. Low.

TESTIMONY OF GEORGE M. LOW, CHIEF, MANNED SPACE FLIGHT PROGRAM, NASA

Mr. LOW. Mr. Chairman, our first four presentations this morning are on the subject of manned space flight, which is one of the ultimate objectives of all of our space activity.

When Dr. Dryden testified before this committee, he gave a brief outline of our manned space flight program. This morning we would like to quickly review the highlights of Dr. Dryden's testimony, before going into further detail of some of the other aspects of the program.

To put things in a proper perspective, I would first like to outline the steps, or milestones, in our long-range program, and I have listed these on a chart.

At the top of the chart we have the X–15 research airplane, which is now being readied for its first flight tests. But the first orbital flight will come at the culmination of Project Mercury, which is our manned satellite project, and this we will discuss in much more detail later on this morning.

Although Mercury constitutes a logical and perhaps the only first step in our manned exploration of space, we are already studying more advanced systems; I refer in particular to satellitie vehicles that will have the capability of maneuvering once they reenter the atmosphere so that they can land at a small preselected site.

Then, as more advanced boosters become available, we will develop the capability of sending several men into orbit for longer periods of time than 1 day. We will then be in a position to conduct scientific experiments in a series of manned orbiting laboratories. The ultimate such laboratory will be a permanent manned space station which will be resupplied periodically from the ground.

Concurrently, we will make efforts to fly further away from Earth, perhaps to the vicinity of the Moon; but a landing on the Moon must await the development of boosters that are nearly 20 times as powerful as those that are available today.

The last item on the chart is interplanetary flight which is, of course, the goal of our manned space flight efforts.

Let me return to orbital flight with the simplest vehicle, or Project Mercury. This is a very active project now, with the objectives of achieving manned orbital flight and successful recovery at the earliest possible date, and to study man's capabilities in the space environment. I would like to ask Mr. Faget, who is chief of the Mercury Flight Systems Division, to discuss the technical details of Project Mercury.

Introduction to
MANNED SPACE FLIGHT

MANNED SPACE FLIGHT
MILESTONES

A. SHORT RANGE FLIGHTS (X-15)

B. ORBITAL FLIGHT - SIMPLEST VEHICLE

C. ORBITAL FLIGHT - ADVANCED CONCEPTS

D. ORBITAL FLIGHT - SEVERAL MEN FOR SEVERAL DAYS

E. PERMANENT MANNED ORBITING SPACE LABORATORY

F. MANNED FLIGHT TO VICINITY OF MOON

G. MANNED LANDING ON MOON AND RETURN

H. INTERPLANETARY FLIGHT

Senator STENNIS. Thank you, Mr. Low.
All right, Mr. Faget, we are glad to have you, sir.
Mr. FAGET. Thank you, sir.

TESTIMONY OF MAXIME A. FAGET, CHIEF, FLIGHT SYSTEMS DIVISION, SPACE TASK GROUP, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. FAGET. This first chart is a picture of the Mercury flight system which will consist of the Atlas booster, the manned satellite, which is sometimes termed the space capsule, and an escape system.

Now, the particular type of manned satellite that we have chosen is a ballistic re-entry vehicle. What this means is that during reentry into the atmosphere, the vehicle does not use lift. It merely comes into the atmosphere without lifting and depends on atmospheric drag to decelerate it down to zero velocity, or near zero velocity for parachute deployment.

The reasons we chose this particular type of vehicle were as follows: Such a vehicle is considerably more compact and lighter than the more sophisticated lifting types of vehicles, and for this reason it was easy to incorporate it with an existing booster system, namely, the Atlas, as shown here.

This saved not only development time and expense, but it also enhances our chances of success, inasmuch as we are exploring the unknown with the least amount of new developments in proceeding in this manner.

BALLISTIC CAPSULE

Let's look a little more closely to some of the details of our space capsule. Shown in the next chart is a cross-section, and I would like to point out here it is merely diagrammatic. It is not an actual scale view of the capsule which is now in the design phase, and is changed from day to day. However, I think it shows all the important aspects of it.

First, from a structural standpoint, the man is contained in a double wall pressure vessel shown in here. This pressure vessel will be made with a double skin of titanium, and it will be enclosed in a heat-protection vessel, the lower part of which is what we call heat shield. This is a thick piece of material that absorbs the majority of the heat energy which is produced during reentry into the atmosphere. I should point out the capsule enters flying in this direction, with this large, heavy shield forward.

Now, like I say, this absorbs a majority of the heat energy. However, there is some heating in the rear portion which is taken care of by a very thin high-nickel alloy material which is capable of dissipating this heat by radiation out into space.

Between the heat-shielding material and the pressure vessel we have insulation which also serves as acoustical dampening material. In other words, we reduce the sound intensity from the booster during the boosting phase of the flight and will reduce the amount of aerodynamic noise during the entry, thereby making the flight more comfortable and enhancing the possibility of communicating with the ground station.

This multiwalled type of construction, I would like to point out, is also favorable from the standpoint of reducing the chance of a meteorite penetration of the pressure vessel. In other words, the outer shield and acoustic material will tend to slow these meteorites down, and we are fairly confident there is no chance at all of a meteorite penetration.

I will now briefly describe some of the other systems on board. First, we have a couch which the pilot is supported in. This couch, as you probably heard before, is designed to minimize the effects of the high acceleration loads on the pilot. We have a communications system which allows him to keep in contact with the ground. Mr. Mathews will go into the aspects of the ground stations which are used to keep in communication with the satellite, in his presentation.

One of the more interesting systems aboard is the attitude control system, which consists of small pitch and yaw jets up in the upper portion here, and some roll jets. These are really minute rocket motors which use hydrogen peroxide as a propellant, and they are operated in response to an autopilot which is carried aboard. This autopilot is directed by a horizon scan system which is sensitive to infrared rays and is capable of sensing the horizon; the horizon scan system continually keeps the autopilot properly oriented. In other words, tells the autopilot which way is up. The autopilot operates the roll, pitch, and yaw jets that keep the capsule stable so that when it is in orbit the satellite will be in this position with the man sitting down with the earth below.

I would like to point out that we have a periscope here and a manual control system that the pilot can use to do the same thing that the autopilot does, namely, stabilizes the attitude in space.

Senator STENNIS. Does what?

Mr. FAGET. Stabilizes attitude in space, keep himself upright in space using another set of control jets and looking at the earth's surface through his periscope, and he will have two windows, also, but the periscope is so arranged as to optimize the earth display to make this job easier for him.

To reenter the atmosphere we use retrorockets. I will go into that later in the next chart to point out how that operates. After reentering, the atmospheric drag slows the vehicle down and at 60,000 feet we deploy a small drogue parachute which is used to descend to an altitude of 10,000 feet, at which altitude the main parachute is deployed and the capsule will normally land in the ocean, on the water. In the event of a parachute failure, we have a complete duplicate set of parachutes which the pilot may operate.

FLIGHT TRAJECTORY

This chart shows a typical flight history of the capsule starting off with a launch from Cape Canaveral, which is where we are going to launch this, inasmuch as this is where the capability to launch the Atlas booster exists.

I would like to point out that throughout our program we are trying, in order to minimize the amount of time, to use whatever capability exists wherever it exists.

The Atlas booster, as you probably know, has a three-engined configuration. The outer two engines, termed booster engines, each

capable of producing 150,000 pounds of thrust. The inner engine, which is a sustained engine, is rated at 80,000 pounds of thrust. In launching, all three engines are lit and will continue to burn for about two minutes, at which time the capsule is about 40 or 50 miles above the earth's surface.

At this time the booster engines are turned off and jettisoned. This is the staging period. The sustainer engine, however, does continue to operate. Shortly after staging we get rid of our escape tower which is no longer needed outside of the atmosphere. This is also jettisoned.

The sustainer engine continues to operate, and will bring the vehicle up to orbital velocity, at which time the capsule will be separated from the booster by some small separation rocket motors. Immediately after separation the capsule will change its attitude from the direction on the booster to the opposite direction. It will continue in this attitude from 2 to 16 orbits, pending on the mission chosen. We will be able to stay in orbit a little bit over a day.

In order to return to Earth the retrorockets are fired. These retrorockets change the velocity of the capsule by about 350 miles an hour. This change in velocity is enough to reduce the forward velocity to an amount that is less than able to keep it in orbit, and its starts to fall into the atmosphere. The retrorockets are jettisoned prior to reentry of the atmosphere.

The atmospheric reentry, as I pointed out, is accomplished in a ballistic manner where air drag is used to reduce the forward velocity, the parachute is deployed, it lands on the water where recovery operations take place. The recovery operation will be discussed in a talk immediately following the one I am giving.

ESCAPE SYSTEM

Now, in the event of the failure of the Atlas system, we have provided an escape system for the astronaut. As I pointed out we are trying to accomplish this job on a minimum time basis. Therefore, we are using what is available; namely, the Atlas booster.

Senator STENNIS. Speak just a little louder, please.

Mr. FAGET. Yes, sir.

We are using the Atlas booster, which is the one that is available now, and indications are that even when we are ready to launch Mercury the Atlas will not be completely reliable. There is certainly a small chance of failure of the rocket. For that reason, we have provided a means for the pilot to escape from the vicinity of the rocket motor during the boosting phase of the flight.

This is accomplished with a small rocket motor mounted on a tower type arrangement at the front end of the capsule. In the event of an impending failure, which can be sensed with various instrumentation on the booster, or on the ground with our tracking and launching complex, the abort system will be triggered. This will fire the escape rocket and will pull the capsule away from the booster at a velocity of again around 350 miles an hour relative to the booster. As a matter of fact it will put 250 feet between the escape configuration and the booster during the first second, which is more than enough to get it out of any danger.

After the escape rocket is fired the tower will be jettisoned; after it is jettisoned the attitude is not stable, so that the capsule will turn around. After the attitude changes, the parachute is deployed, and the landing and recovery would be made in the normal manner.

ORBITAL FLIGHT PATHS

This next chart gives you an idea of what the orbital flight path will be for what will probably be our first orbital mission.

The launching, as I pointed out, will be made from Cape Canaveral. It will be launched a little bit north of due east over the Atlantic Ocean. You see here a series of ships deployed out in the Atlantic Ocean. These ships are deployed there for purposes of immediate down-range tracking and for the purpose of picking up in the case of an abort during the launching phase. This will be gone into some further extent by Mr. Mathews.

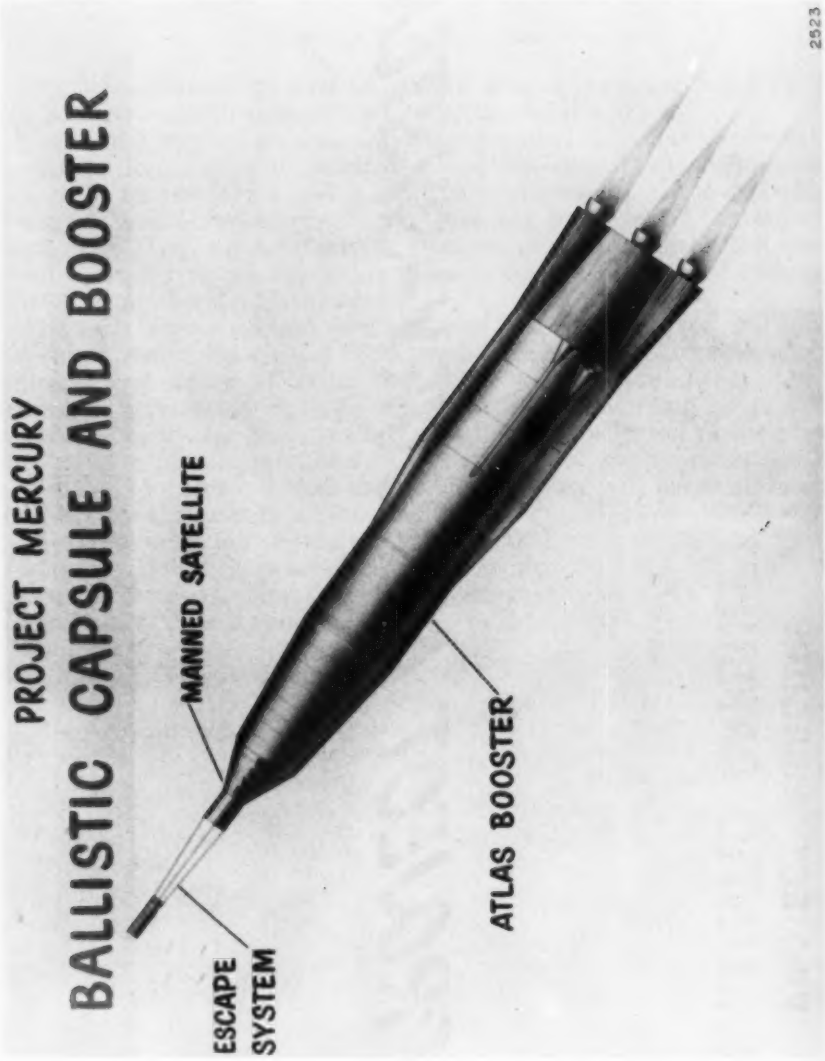
The vehicle goes around several times, and the final pass which is the third pass, comes just a little north of Hawaii. The retrorocket is fired about 400 or 500 miles west of the west coast, and then it re-enters the atmosphere over Florida, and the final landing point will be in the same area that has been used successfully for picking up our ballistic missile nose cones during the past year. However, I would like to point out that the pickup complex will be much more complete for this particular mission.

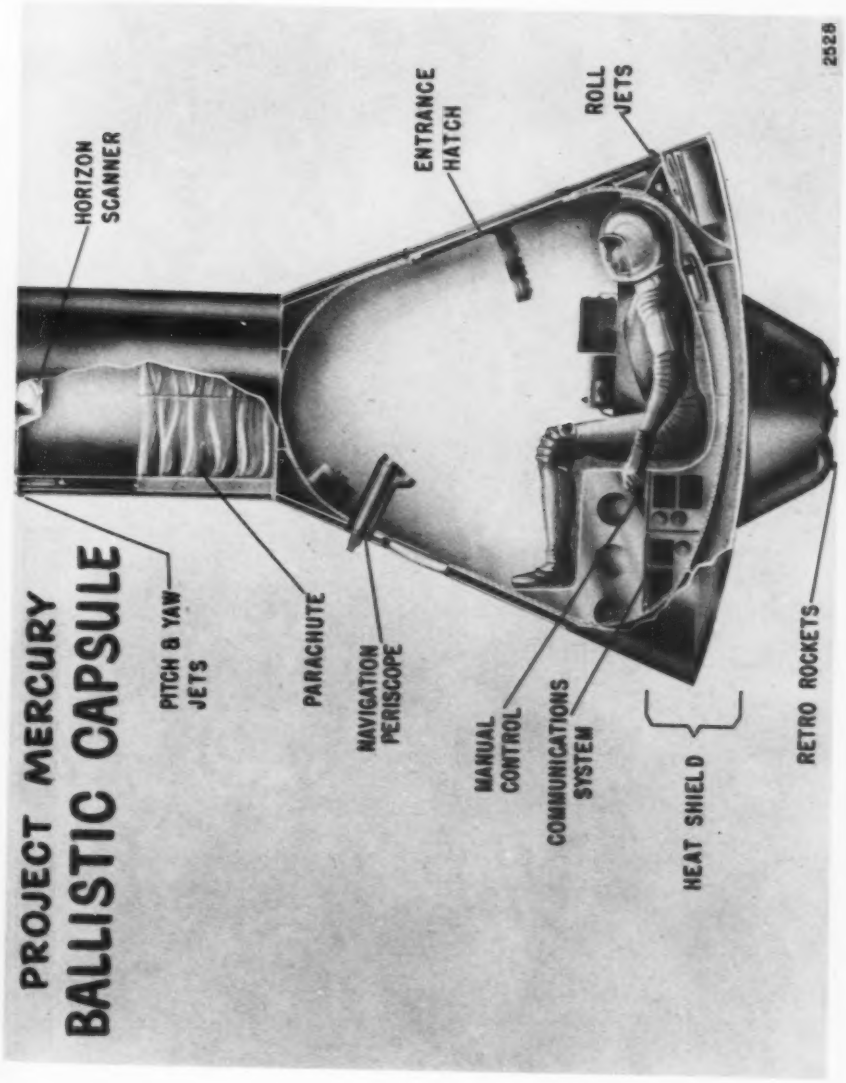
That concludes my presentation. I think I will turn it back over to Mr. Low, unless there are some questions, sir.

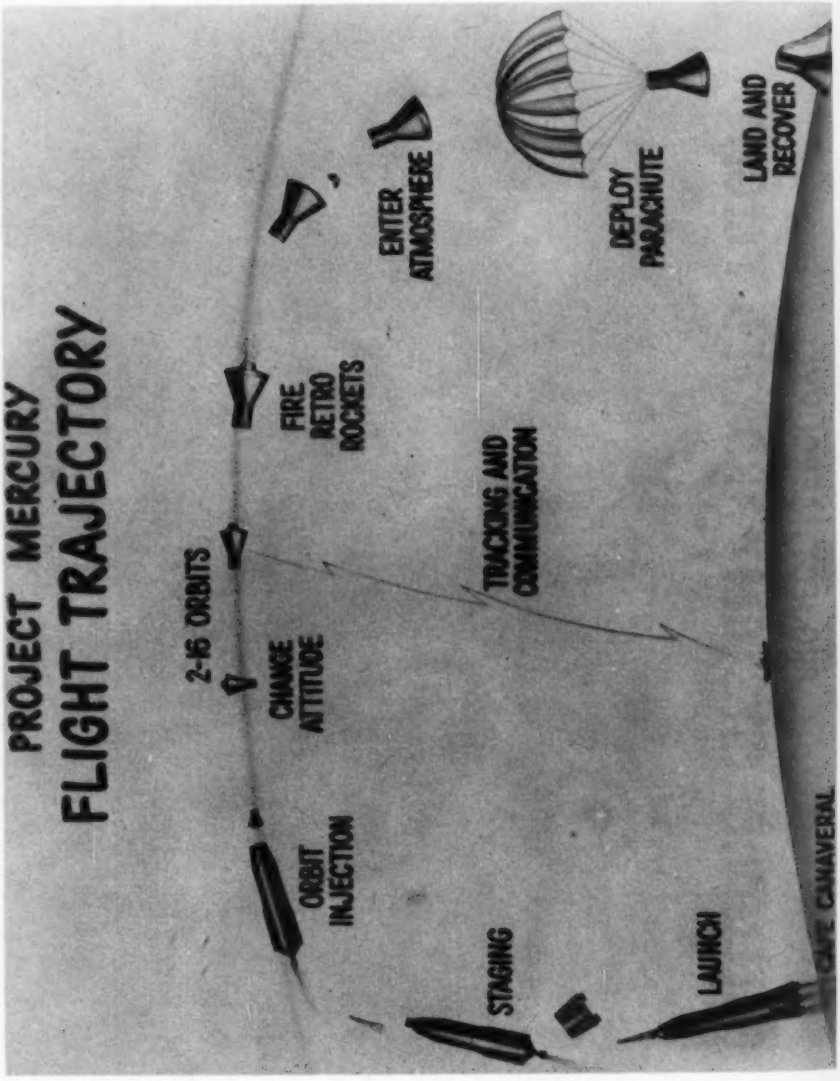
Senator STENNIS. That is very interesting.

Mr. FAGET. Thank you.

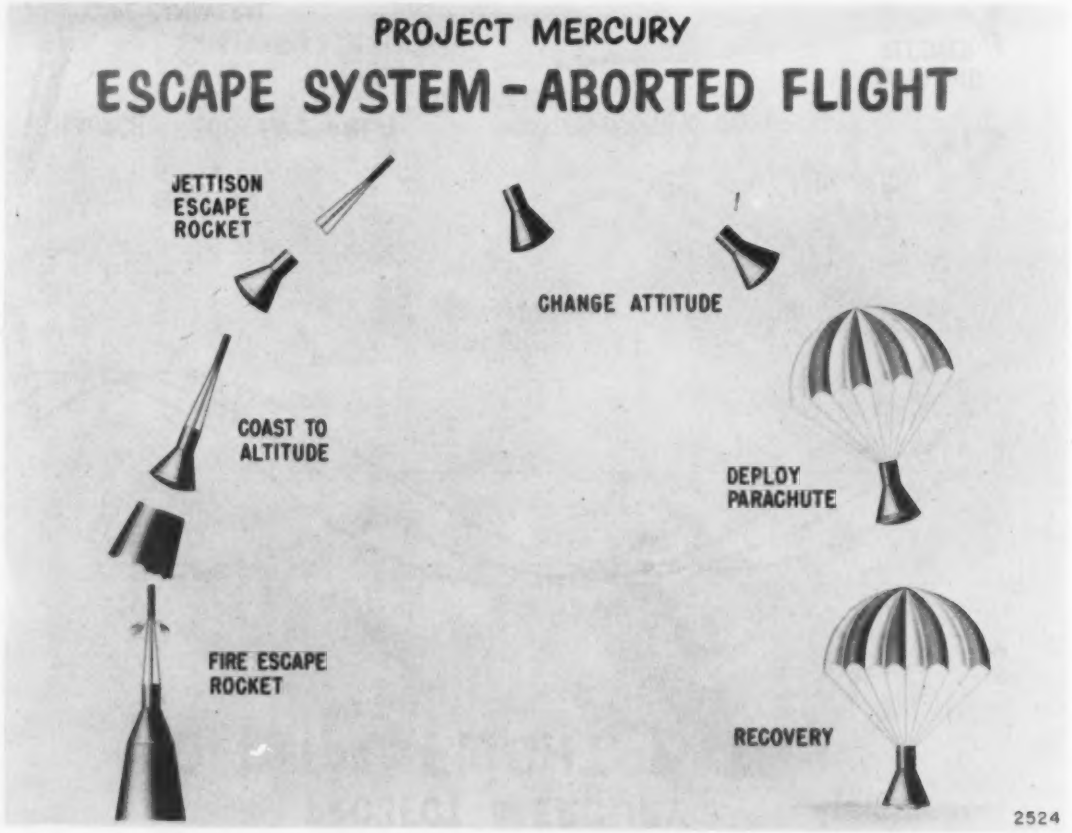
PROJECT MERCURY-SYSTEM


PROJECT MERCURY
BALLISTIC CAPSULE AND BOOSTER
MANNED SATELLITE
ESCAPE SYSTEM
ATLAS BOOSTER
2523


PROJECT MERCURY
BALLISTIC CAPSULE
HORIZON SCANNER
PITCH & YAW JETS
PARACHUTE
NAVIGATION PERISCOPE
ENTRANCE HATCH
ROLL JETS
MANUAL CONTROL
COMMUNICATIONS SYSTEM
HEAT SHIELD
RETRO ROCKETS
2528


PROJECT MERCURY
FLIGHT TRAJECTORY
STAGING
ORBIT INJECTION
2-16 ORBITS
CHANGE ATTITUDE
FIRE RETRO ROCKETS
ENTER ATMOSPHERE
TRACKING AND COMMUNICATION
DEPLOY PARACHUTE
LAND AND RECOVER
LAUNCH
CAPE CANAVERAL

RECOVER
CAPE CANAVERAL


PROJECT MERCURY
ESCAPE SYSTEM - ABORTED FLIGHT
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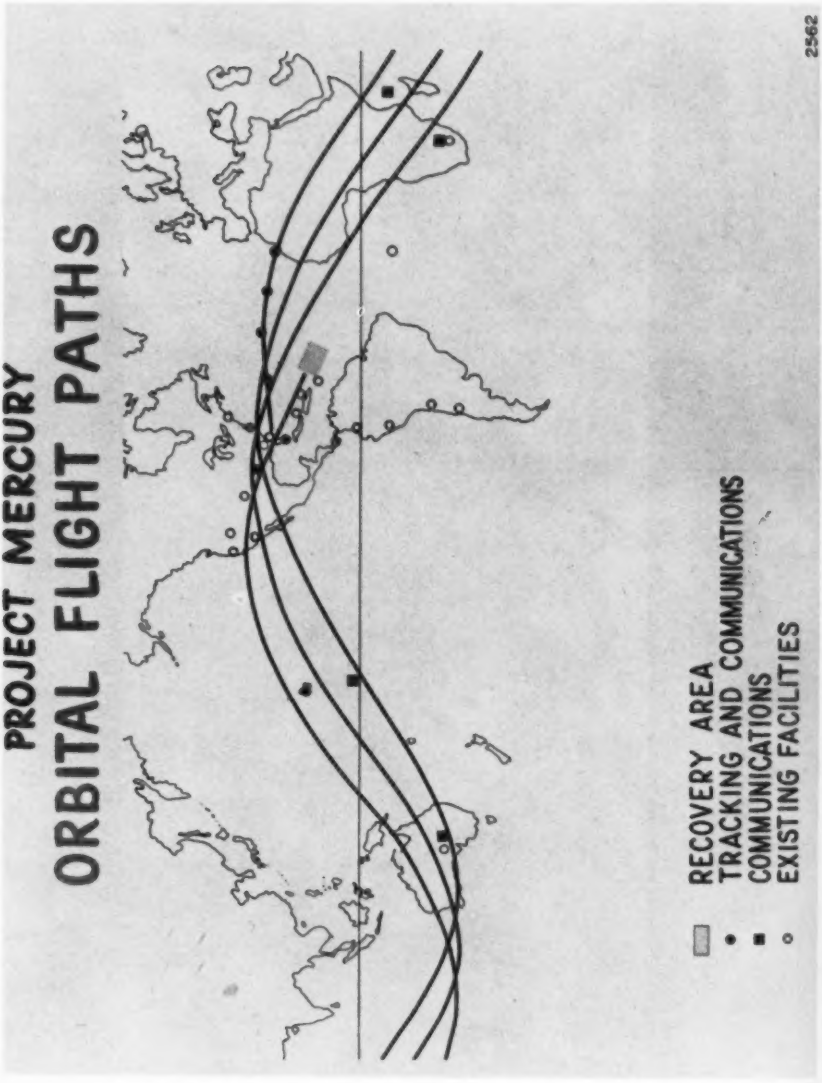
CHANGE ATTITUDE
COAST TO ALTITUDE
DEPLOY PARACHUTE
FIRE ESCAPE ROCKET
RECOVERY
2524


PROJECT MERCURY
ORBITAL FLIGHT PATHS
RECOVERY AREA
TRACKING AND COMMUNICATIONS
COMMUNICATIONS
EXISTING FACILITIES
2562

Senator STENNIS. We thank you very much. There may be some questions later, if you will stay with us.

Mr. FAGET. Yes, sir.

Mr. LOW. The next speaker, Mr. Chairman, is Mr. Charles W. Mathews, who is Chief of the Flight Operations Division of Project Mercury. He will discuss the operating concepts behind the Mercury system.

Senator STENNIS. All right, Mr. Mathews, glad to have you here, sir.

Mr. MATHEWS. Thank you, sir.

Senator STENNIS. What is the meaning, now, being Chief of the Operations Division? Are you Chief out in the field projects, or the laboratory projects, or both?

TESTIMONY OF CHARLES W. MATHEWS, CHIEF, OPERATIONS DIVISION, SPACE TASK GROUP, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. MATHEWS. This is connected with Project Mercury, of course, and the Operations Division of which I am Chief has the responsibility for the actual flight test work that goes on. It also embodies concern with the worldwide range for this orbital flight, and problems of training the crews, and so forth.

Senator STENNIS. All right.

Mr. MATHEWS. A very important phase of the Project Mercury program is the flight program, itself.

FLIGHT TEST PROGRAM

The program involves a gradual buildup to this ultimate mission; in other words, we are not jumping right into the orbital mission. There is a very complete buildup program that will validate our approach. In fact, this first chart indicates the phases of our flight program.

The first phase that is already underway is a series of developmental tests of full-scale capsules, but these capsules are what we call boilerplate capsules. They are cruder devices than the one that we will ultimately use. They can be put together in a hurry to check out various features of the mission. In doing this we will establish design criteria to lend guidance to the manufacture of our final capsule, to aid in its component development, and to help make sure the reliability of the system is satisfactory when we finally get it.

When we do get the capsule that is being manufactured by McDonnell, it again will undergo a very vigorous test program that will involve qualifying it to make sure it is right, and of course this will involve all the final hardware, the capsule itself, and all the equipment on board. A part of this program involves a series of animal flights. The animal flights will be used to make sure that the environmental control, that is, the system on board that supports the life of the human, is operating satisfactorily. The animal flights will also establish that some of the critical and stressful areas that are associated with the mission, such as the high acceleration conditions, and the condition of weightlessness, are satisfactory.

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Having qualified our system, then, there is another part of our buildup program that involves actual piloted missions. Before going into orbit there will be a number of flight tests that will involve the training of the pilot.

A part of this training program will actually see how well he can do certain tests that are associated with this mission. In other words——

Senator STENNIS. Mr. Mathews, pardon me just a minute. These gentlemen over at the press table are interested in certain phases of this. Could you turn your easel just a little so as to include them, too? We can see it very well, indeed.

Mr. MATHEWS. We are trying to qualify the pilot, himself, in other words. We are trying to see just what he can do in this new environment, and we hope he can take over some of the tasks and thereby increase the reliability of the mission.

In fact, the capsule we are procuring has considerable equipment on board which will let him perform certain functions if we can verify that he can do this.

DEVELOPMENT TESTS

As an illustration of some of these development tests, the next chart shows an airdrop test that we have had underway. These airdrop tests involve a full-scale boilerplate capsule which is dropped from a C–130 airplane, a fairly large airplane. The purpose of the test is to check the motions of the capsule in the terminal phases and the operation of the parachute system and the landing on water. This is exactly the same kind of situation we have in the terminal phases of the orbital mission.

You can see the capsule impacting here. The chute is jettisoned just after it impacts. This airplane shown on the chart is a chase airplane that continuously circles the capsule and takes pictures so we can tell just what is going on.

There are a number of other parts of this program that we are working on. We are working on studying escape problems with these boilerplate capsules, firing the system off the beach at Wallops Island. This simulates the condition where we would have to get off the Atlas at the time the Atlas is tied down to its pad.

We also have as part of our development program balloon flights which can check out the environmental support system in a near space environment.

ROCKET FLIGHT TEST VEHICLES

However, I think the most important part of our flight program involves the ballistic flights that are being accomplished with this stable of vehicles shown on the next chart. As you can see, there are quite a few, and the reason there are quite a few is that there are certain things that can be done with these small vehicles that can validate our operation, and although they could be done with the Atlas, they can be done much cheaper with the small vehicles.

For example, this vehicle is a cluster of four solid propellent rockets housed in a cylindrical section—we call it Little Joe. This vehicle can be procured for about a sixth of the price of an Atlas.

Now, Little Joe can boost a full-scale capsule to about 4,000 miles an hour. We can therefore simulate the escape conditions where we have to separate the escape capsule and make sure it separates. There are a number of conditions that we call maximum Q conditions, which means the loads are the worst, which we can investigate with Little Joe. We can also investigate how the capsule behaves on reentry, because we can project this vehicle out of the atmosphere and have it come right on back in.

Another vehicle involved in our vehicle test program is the Atlas itself. The reason we have to go to the Atlas is that in this particular part of the program we plan to check on how we are protecting this capsule from heat. The severe heating conditions, of course, are associated with going right on up to orbital speed, or about 18,000 miles an hour, and the Atlas is the only one of these vehicles that can do that. But instead of putting the capsule into orbit, we send the capsule up to orbital speed, but we immediately send the capsule back down on a reentering trajectory. This is just like if the capsule had returned from orbit and the heating that we get is exactly the same as if we were returning from orbit.

Now, the Jupiter is involved in qualifying the final capsule. There is a particular condition that exists that is fairly critical from the load standpoint. That occurs about 12,000 miles an hour. If the capsule has to escape from the Atlas at that speed, it will reenter at a much steeper angle than it would if it had gotten all the way into orbit and returned; this results in the biggest load of all, about 20 g. in the capsule during this reentry. We can get this same condition with the Jupiter, which is a considerably cheaper missile than the Atlas, and in our qualification program we will be using the Jupiter to investigate that particular problem to make sure our escape system operates satisfactorily, if such a condition should occur.

Now, the Redstone will be the first vehicle that will be used for piloted operation. First we will qualify the capsule Redstone combination in unmanned flights, and then there will be some flights with animals, as I mentioned. But the reason we chose the Redstone for our first piloted flights is that it is the missile that has had the most experience behind it. It is already highly reliable, and it has some very nice features from a manned operations standpoint. These fins on the back give it aerodynamic stability. It is stable all by itself during the launch, whereas these bigger vehicles; they depend on an automatic system to keep them stable.

So this is the vehicle we will use, and the reason we want to have the pilot involved in an operation of this type is the one I mentioned before; we can find out just what the pilot can do. Can he hold the attitude of this capsule properly; can he change its attitude. He will be subjected to high-launch accelerations, and then 5 minutes of weightlessness, and then he will be subjected to high accelerations during the coming back in. So this is the type of program we have.

Now, it involves a fairly sizable recovery effort. The Redstone and the solid rocket Little Joe booster boost the capsule up to about 4,000 miles an hour and they go into a ballistic lob, sort of a baseball type throw that impacts about 130 miles from where they are launched. The Jupiter, however, which goes up to 11,000 or 12,000 miles an hour, impacts about 1,200 miles down range; and then the Atlas flights,

that go all the way up to orbital speed and back in, go about 1,700 miles down range.

With the exception of Little Joe, all these operations will take place along the Atlantic Missile Range, and although we have to mount recovery effort in these areas, which I show, each one of these areas is a satisfactory area in terms of Atlantic Missile Range capability, and recoveries have taken place in these areas in the past.

PILOT SELECTION

I think I mentioned to you that we are hoping the pilot can take a big part in this mission, and thereby increase its reliability, and I also mentioned that we have equipment on board that will let him perform certain functions, if we can justify his doing it.

Just to give you a feel for the kind of things we would like to have this pilot do, and what he can do if we can qualify him, there is a list of eight things on the next chart. First, in any case we will want him to communicate with ground stations, and we will have ground stations all the way around the world. He will be over stations for about a 5-minute period, and he can talk to them continuously for about 5 minutes. There will be, however, cases where he will not be able to talk to people for the order of about 10 minutes. The spread of the stations is such that this is the situation.

We would like to plan to make scientific observations in terms of our objectives with this program. It will be the first chance a man has had to be in this position for any length of time, to observe the earth and observe the stars and so forth. We would like to have him qualified so that he can come back with whatever information he can obtain from his observations, meteorological information, for example, cloud cover, and certain things as regards the observation of other planets, without having to worry about the obscuring effects of the atmosphere.

Now, the other things down here are more associated with his job as a pilot. He will monitor onboard equipment. He will see that equipment is operating properly, and if it isn't, he will initiate emergency procedures; we will have a training program to make sure he knows what to do.

We will have backup capability of flying the capsule, that is, controlling its attitude, and he will be able to navigate to the extent that he will be able to determine where he is at any particular time. He will be able to predict just where he is going to be so that he can determine where to fire the retrorockets to bring him back in at the proper point.

He will have backup provisions to escape if he decides that the situation requires an escape, and to deploy the landing parachutes if he decides that our automatic deployment system is not functioning properly.

You can see that if he can truly perform these things he can greatly enhance the reliability of the mission, and in our selection program to select the people, we took into account the fact that we would like people highly qualified to do these kinds of jobs.

So, to go into that just a bit, I have here a short list of the kinds of requirements we put on people we ultimately selected. Because this operation is a pretty stressful operation, we wanted him to be a reasonably young man, less than 40. Simply because of the size of the capsule we had chosen to build, he had to be less than 5 feet 11 inches. He had to be in excellent physical condition. This is also because of the stresses involved. Because of the requirement to contribute scientifically to the program, we required that he have a bachelor's degree in either science or engineering, so that he can understand the development that is taking place.

Because we wanted him to have previous experience in stressful activities, and because it is very much like an airplane-type operation that we are talking about here, we asked that he be a graduate of a test pilot school with 1,500 hours of flying time, and be a qualified jet pilot.

Senator STENNIS. Excuse me just a minute.

Mr. MATHEWS. Yes.

Senator STENNIS. Mr. Low said they were going to announce these seven names at 2 o'clock, three from the Air Force, three from the Navy, and one from the Marines. I don't know whether it is wise to announce their names or not. Would that complicate your problem?

Mr. LOW. It would be awfully difficult, Mr. Chairman, not to announce their names, because we cannot keep them hidden away until the flights are made.

Senator STENNIS. I was afraid it would complicate your problem, but you think it necessary. Well, that is all right.

Mr. LOW. I think it is essential. Incidentally, it is my understanding that their names will be supplied to the committee members at 2 o'clock this afternoon.

Senator STENNIS. Thank you, Mr. Low.

All right, proceed.

Mr. MATHEWS. I don't have too much more to say except to go over just where we stand on this project. I think I went over this a little before, so I won't dwell on it.

Since NASA was organized in October, we got to the point where we have a contractor for this capsule, and he is proceeding along at a rapid rate to the point where we have had a mockup, a rather complete mockup of this capsule built and we have inspected it. As far as our development test program is concerned, we have a very vigorous wind tunnel program going on to make sure that our capsule aerodynamics are satisfactory. I have mentioned the landing tests. We also have escape tests going on at the present time.

FUTURE PROJECT MERCURY OPERATIONS SCHEDULE

The ballistic flights that will involve development tests will start about the middle of this year, and we will be getting the contractor to furnish capsules soon enough so that we can start qualifying them on Redstone, Jupiter, and Atlas, starting about the first of next year, and ultimately as we move along this will lead to manned flights on the Redstone, and then on the Atlas.

That is all I have to stay.

Senator STENNIS. You mean sometime in 1960?

Mr. MATHEWS. As far as the manned flights are concerned, we will precede these as I mentioned by unmanned flights, and as we move along in the program we will decide that the situation is satisfactory for the man, and this will be decided at that time.

Mr. LOW. I would like to point out, Mr. Chairman, that there are many unknowns in this project, and we cannot predict exactly at this time when we will be able to fly a man.

Senator STENNIS. Yes.

Mr. LOW. It might come earlier than we hope for if everything goes real well, but the chances are that it would take a long time as yet.

Senator STENNIS. It depends entirely upon your developments as you go from one stage to the other?

Mr. LOW. Yes, sir.

Senator STENNIS. All right. Does that finish you, Mr. Mathews?

Mr. MATHEWS. Yes, sir.

PROJECT MERCURY—OPERATIONS

PROJECT MERCURY

PHASES OF FLIGHT PROGRAM

DEVELOPMENT TESTS

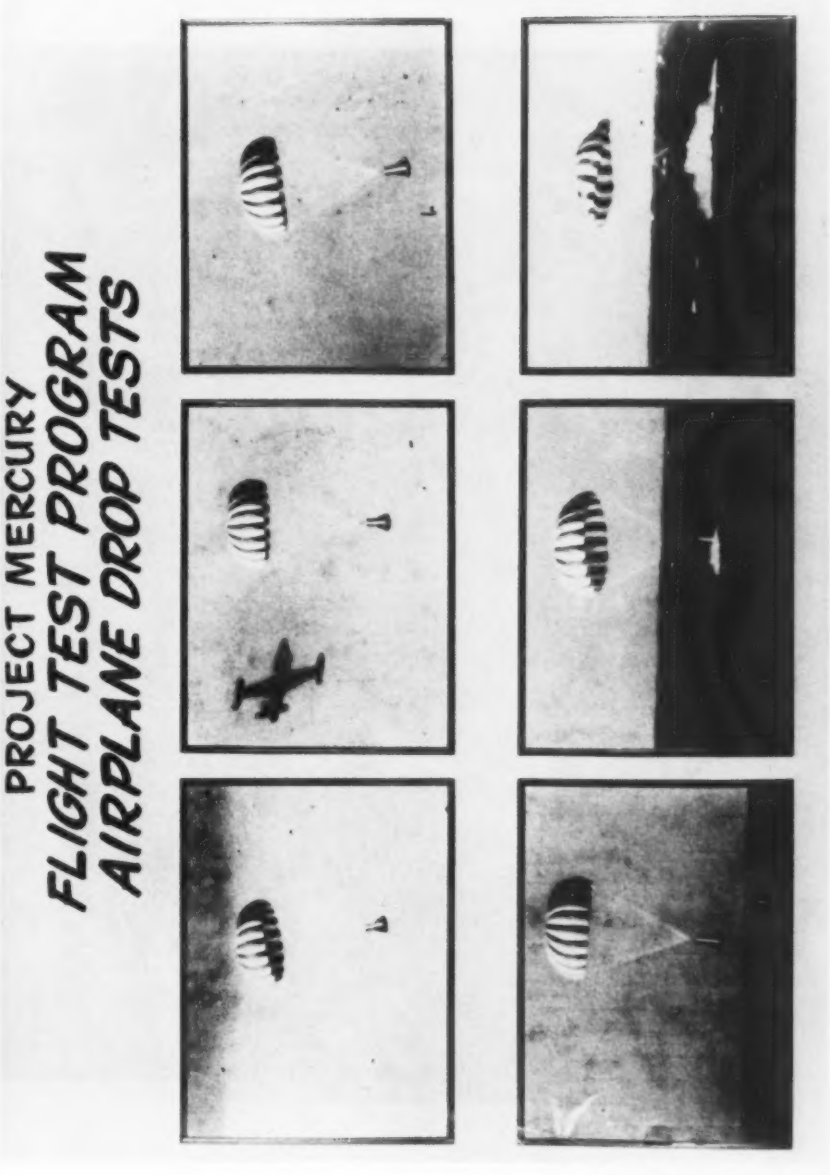
DESIGN CRITERIA
COMPONENT DEVELOPMENT
COMPONENT RELIABILITY

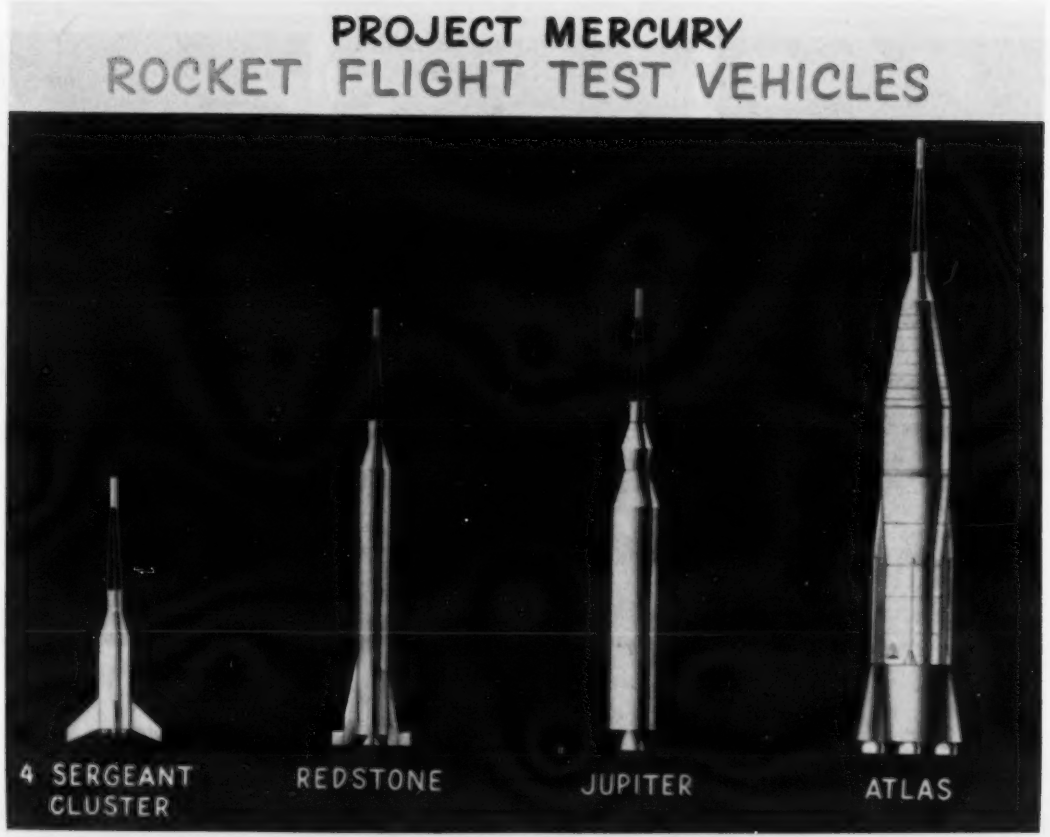
QUALIFICATION TESTS

FINAL HARDWARE
ANIMAL FLIGHTS

PILOT MISSIONS

TRAINING AND SELECTION
TASK PERFORMANCE

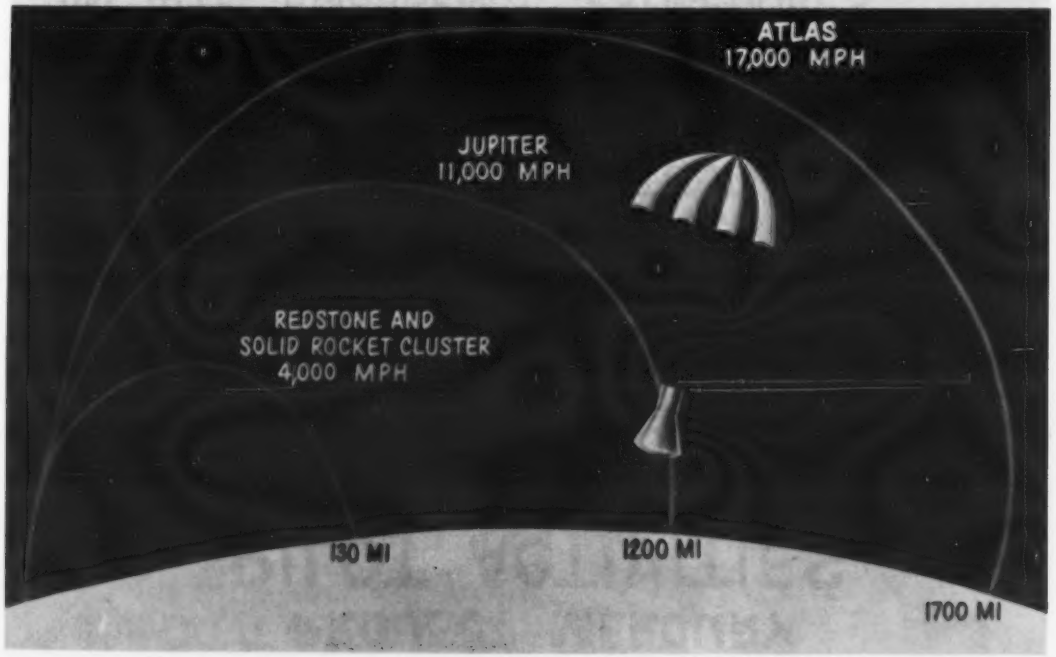

PROJECT MERCURY
FLIGHT TEST PROGRAM
AIRPLANE DROP TESTS


PROJECT MERCURY
ROCKET FLIGHT TEST VEHICLES
4 SERGEANT CLUSTER
REDSTONE
JUPITER
ATLAS

CLUSTER

PROJECT MERCURY

BALLISTIC FLIGHT TRAJECTORIES



PROJECT MERCURY
PILOT ACTIVITIES

1. COMMUNICATE WITH GROUND STATIONS
2. MAKE SCIENTIFIC OBSERVATIONS
3. MONITOR ONBOARD EQUIPMENT
4. CONTROL CAPSULE ATTITUDE
5. NAVIGATE AND FIRE RETROROCKET
6. INITIATE EMERGENCY PROCEDURES
7. ACTIVATE ESCAPE SYSTEM IF REQUIRED
8. DEPLOY LANDING PARACHUTE IF REQUIRED

8. DEPLOY LANDING PARACHUTE IF REQUIRED

PROJECT MERCURY

CRITERIA USED IN PILOT SELECTION

1. AGE - LESS THAN 40
2. HEIGHT - LESS THAN 5'11"
3. EXCELLENT PHYSICAL CONDITION
4. BACHELOR'S DEGREE
5. GRADUATE OF TEST PILOT SCHOOL
6. 1500 HOURS FLYING TIME
7. QUALIFIED JET PILOT

PROJECT MERCURY
MILESTONES

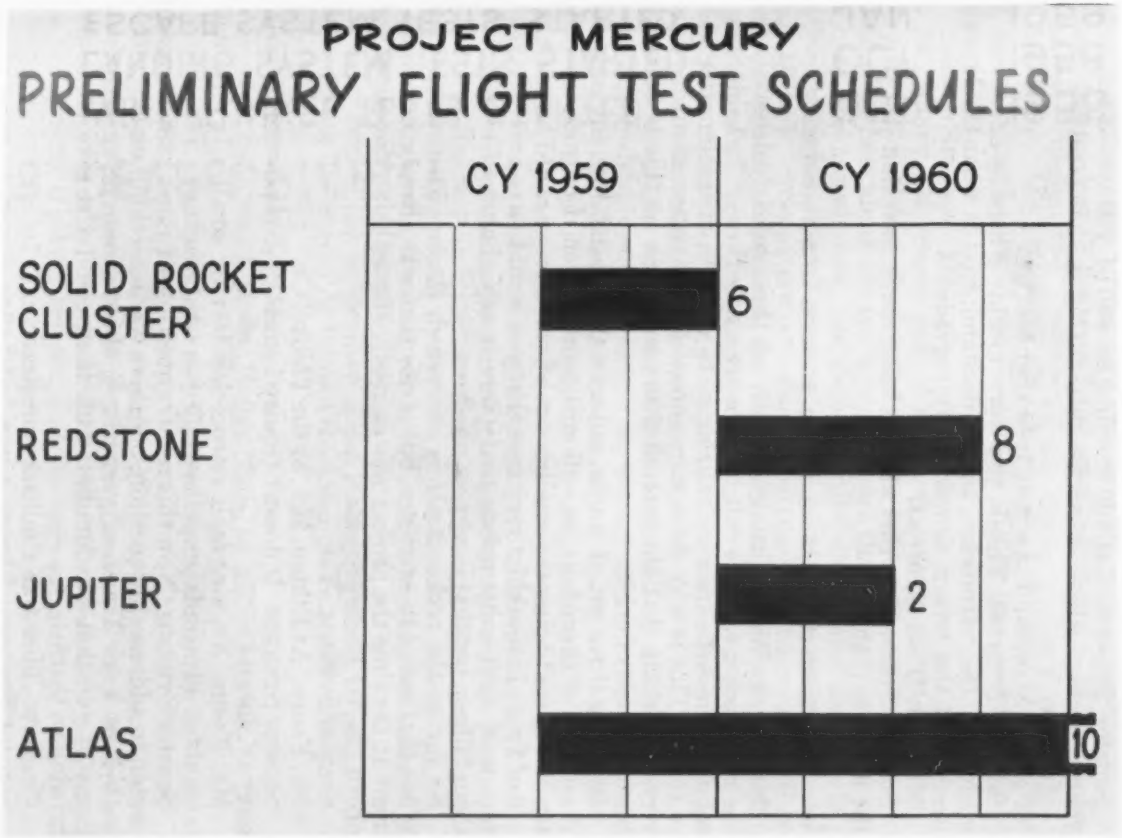
A. CAPSULE CONTRACTOR

NASA ORGANIZED	OCT. 1, 1958
SPACE TASK GROUP FORMED	OCT. 5, 1958
CAPSULE SPECIFICATIONS MAILED	OCT. 23, 1958
BIDDERS CONFERENCE HELD	NOV. 7, 1958
PROPOSALS RECEIVED	DEC. 11, 1958
CONTRACTOR NAMED	JAN. 9, 1959

B. DEVELOPMENT TESTS

WIND TUNNEL TESTS STARTED	OCT. 1958
LANDING SYSTEM TESTS STARTED	OCT. 1958
ESCAPE SYSTEM TESTS STARTED	JAN. 1959

ESCAPE SYSTEM TESTS STARTED	JAN.	1959



Senator STENNIS. Mr. Low, when you come to a breaking point indicate it. Otherwise you may call your next witness.

Mr. LOW. Well, this might be a good point, Mr. Chairman, because the next presentation will concern the biomedical programs.

Senator STENNIS. I think it would be well if you would return to your first chart which shows the man sitting in that position.

Mr. LOW. Yes.

Senator MARTIN. I saw it at an earlier hearing.

Senator STENNIS. Thank you very much. There is one memo I made here, the retrorocket, as I understand, that is what the layman would call the return slowdown, retrograde?

Mr. LOW. That is correct.

Senator STENNIS. Is that already being made, or is that just part of the ultimate plan?

CLUSTER OF THREE SOLID FUEL ROCKETS IN RETROPACKAGE

Mr. FAGET. We are using a cluster of three solid fuel rockets for the retropackage, as we call it. We are using three. To begin with, solid fuel rockets are very reliable as to ignition characteristics, and so forth. This is why three were chosen for the retromaneuver. It is very important that the retrocket fire inasmuch as this is bringing him down out of orbit.

By using three we, of course, enhance their reliability, inasmuch as if any one of them fails, he will still return; even if only one were to fire it will still bring the satellite out of orbit, so we could have a failure of two. It would be very rare that you would have two fail. The fact is, I don't contemplate that there is any chance of even one of them failing, but that is why we use three.

So far as the rocket itself is concerned, the one that was chosen is one that is not in existence, but is one that was already in development at the time the project was started. It was being developed for one of the Air Force projects.

Senator STENNIS. Yes.

Mr. FAGET. At Elkton, Md., by the Thiokol Co.

Senator STENNIS. It doesn't require a great deal of power relatively, anyway, does it?

Mr. FAGET. No, sir; each retrorocket is very small. It only contains about 40 pounds propellant apiece, a small package.

Senator STENNIS. Now this reentry question—I don't know to which person to address this question, but there was something on this morning's New York Times, or yesterday's, about a cone being recovered. Some of you that are familiar with that, could you give us a little briefing on that?

Mr. LOW. That was a military project.

Senator STENNIS. I know it was, but I thought maybe some of you would be familiar with it.

Mr. LOW. I am not familiar enough with it to know whether we can discuss it in an open session, Mr. Chairman.

Senator STENNIS. I beg your pardon.

Mr. LOW. I think this may be classified information.

PROCEDURE FOLLOWED IF CAPSULE FAILS TO ACHIEVE ORBITAL VELOCITY

Senator STENNIS. All right, very well. You were talking awhile ago about this vehicle that goes beyond the atmosphere—suppose it doesn't go into orbit. I am sure you have guaranteed against such a possibility as that. How would you guard against it? Will you discuss that some for us?

Mr. FAGET. Mr. Chairman, this chart here, I think it would be best to look at this; I pointed out the capsule will be launched from Cape Canaveral.

Senator STENNIS. Yes.

Mr. FAGET. Of course, one of the most serious things that could happen is that it just didn't quite get into orbit. In that case it could land anywhere along the track here, except that the way we have arranged the system now, the capsule will be separated immediately after the rocket ceases thrusting. As I pointed out, we will change our attitude immediately into the retroattitude. The rocket will be tracked by an Azusa system, the General Electric guidance system, and several radars from Cape Canaveral. In addition at Bermuda there will be another radar tracking it, and the fact that it has not achieved orbital velocity will be determined immediately.

In this event the retrorocket will be fired, and by firing the retrorocket immediately we can contain the impact area for this nonorbital trajectory within the Atlantic Ocean. As a matter of fact, by carefully determining the proper time to fire that retrorocket, we can pick our spots. We have four ships deployed here as pickup areas, and we can tell the retro when to fire in the event we don't make orbital velocity. We can determine how much we missed it by, and there will be a certain time in which you fire that retrorocket and you land in one of these areas here where we are ready to make the recovery.

Senator STENNIS. That is very good. My time is about up, so if you will answer this question briefly:

You answered the proposition about its falling short of going into orbit. Suppose it goes on beyond the atmosphere but doesn't go into orbit?

Mr. FAGET. Goes beyond the atmosphere——

Senator STENNIS. I mean, it just fails to go into orbit, it goes beyond.

Mr. FAGET. You meant if it went into an escape maneuver?

Senator STENNIS. Yes.

Mr. FAGET. This is what we would call an overspeed case. This is not serious. The perigee altitude is determined at the time the rocket burns out. Actually, the whole flight of the Atlas booster is monitored by the ground tracking system, and the burnout altitude will be in the neighborhood of 100 nautical miles. If it deviates from that path seriously prior to getting to maximum speed, we will abort the mission. We have this capability from the ground by command system.

However, if it achieves this altitude but then goes in an overspeed case, the apogee altitude, this is our altitude on the far side of the Earth will be higher. But after it makes one turn around it will return to this same launching altitude.

In other words, by going to overspeed you cannot exceed the launching altitude at least in one part of the mission. What this means, we can still with the retro package, still return to the impact area.

Senator STENNIS. Thank you.

Senator Smith.

Senator SMITH. I have no questions.

Senator STENNIS. Senator Martin.

OF EXISTING VEHICLES ONLY ATLAS CAN PUT SATELLITE INTO ORBIT

Senator MARTIN. Is the Redstone the smallest one that will carry this main head into space?

Senator STENNIS. The capsule?

Senator MARTIN. Yes.

Mr. FAGET. Of the existing rockets used in our ballistic arsenals, you might say, we are using the Redstone, Jupiter, and Atlas, and the Redstone is the smallest of these.

Senator MARTIN. That is right.

Mr. FAGET. However, we are also using this four-rocket cluster which is a very inexpensive way to do part of our test program.

Senator MARTIN. The Sergeant is used to test certain phases of the project, to complete it with a capsule?

Mr. LOW. Only the Atlas can complete the orbital mission; only the Atlas can get the satellite into orbit.

Senator MARTIN. Yes.

Mr. LOW. But none of the others can do that.

Senator MARTIN. Don't you use the capsule on the Jupiter and Redstone?

Mr. LOW. Yes; but it will not achieve a satellite orbit.

Senator MARTIN. But you are not using the capsule at all on the Sergeant cluster; is that right?

Mr. FAGET. Yes; on the Sergeant's cluster we are making four development type flights, with boilerplate capsules. One flight will be made with the Sergeant capsule merely to test out the escape system.

Senator MARTIN. What is that, about four Sergeants wrapped up in one package?

Mr. FAGET. Four Sergeants in one bundle with a metal container on it.

Senator MARTIN. I am trying to get this size on it, the project in mind.

Mr. FAGET. This is about a 40,000-pound vehicle here. This one weighs in the neighborhood of 60,000 pounds. Here you are going up to 80,000, and over to 200,000 with the Atlas.

I might point out an interesting fact about the Atlas. It burns a little over 200,000 pounds of fuel, but on the 24-hour mission the gas mileage, if you want to look at it that way, is a little over 15 miles to the gallon. [Laughter.]

Senator MARTIN. This chart you had here a moment ago showed calendar year 1960 for the beginning of Redstone and Jupiter, preliminary flight schedules, whereas the Atlas you have marked from mid-1959.

Mr. FAGET. Yes, sir; and we are making a couple of flights here in 1959 using boilerplate capsules. These are not the final capsules, but merely a very heavy version of the capsule, that is being used to check out the reentry heating. We use the Atlas because only the Atlas can get it up to the full reentry velocity. These will be ballistic shots with the Atlas, that will go up to orbital velocity, but will only go down range a coupe of thousand miles.

The Jupiter and Redstone are going to come into the program when we have the final capsule ready for them, which is a much more sophisticated thing than we are flying here. Here we only want to check out the heat shield.

Senator STENNIS. All right, Senator, anything else?

Senator MARTIN. That is all.

Senator STENNIS. That 15 miles to the gallon of Atlas, it just shows that the Cadillac and these other big automobiles have a new competitor. [Laughter.]

COMPARISON OF REDSTONE AND ATLAS CAPSULES

Senator STENNIS. May I ask you this: You were talking about the capsules on the Redstone. Is that the same capsule or same type that you will use on the Atlas, or is that an especially smaller version or lighter weight?

Mr. FAGET. No, sir. We are getting approximately a dozen of these capsules from McDonnell Aircraft Co.

Senator STENNIS. I mean, the same type?

Mr. FAGET. They are all going to be identical except for small changes in instrumentation. The point here is to make sure that the capsule system is capable of doing a lot of the operation without expenditure of a full Atlas missile. It is a typical way in what we call a flight buildup program, where we try to achieve more and more stringent goals as we go along.

Senator STENNIS. All right.

At this stage, Mr. Lehrer, do you have any questions?

Mr. LEHRER. No, sir.

Senator STENNIS. All right, Mr. Low, you may proceed. Thank you very much, sir.

Mr. LOW. Mr. Chairman, because man plays such an important part in this project, we rely very heavily on the aeromedical community for advice. In this area the NASA Committee on Life Sciences is particularly helpful, and the next witness is the Deputy Chairman of this Committee, General Flickinger.

General Flickinger is the assistant to the commander of the Air Force's ARDC, and will discuss the biological aspects of Project Mercury.

Senator STENNIS. All right, General.

TESTIMONY OF BRIG. GEN. DON D. FLICKINGER (DR.), STAFF SURGEON AND DIRECTOR OF LIFE SCIENCES, AIR RESEARCH AND DEVELOPMENT COMMAND HEADQUARTERS, DEPARTMENT OF THE AIR FORCE

General FLICKINGER. If I may be permitted a preliminary statement, I would simply like to give assurance to my esteemed colleague,

Mr. Mathews, as regards the capability of our American astronauts to perform all of these required functions.

Now, the Russians may be ahead of us as far as propulsion is concerned, but we can give them cards and spades and beat them on the quality of our human components.

Senator STENNIS. Well, we are encouraged by your fine assurances.

General FLICKINGER. Thank you, sir.

Senator STENNIS. I believe you are correct.

PROJECT MERCURY BIOMEDICAL PROGRAMS

General FLICKINGER. The current biomedical programs are directed primarily to the provision of what we term an adequate margin of safety for our first Mercury space pilots.

Now, when we speak of this adequate margin of safety, we think in terms of a total mission risk hazard no greater than what our research aircraft pilots have been subjected to in our X series of aircraft, from the X–1 through to the X–15.

Further, we attain this degree of safety for our astronauts by a very rigid selection, test, and qualification of both the hardware components involved in the safety of the astronaut, and of course, the human component as well. Both are equally important.

Now, in order to give substance to my statement that the risk hazard involved in Project Mercury will be the same as first flight of research aircraft, it is necessary briefly to discuss some of the hazards involved and the information that we have at hand not only of the human tolerances to these hazards, but of the engineering techniques and methods of maintaining these hazards within known tolerances.

CREW SAFETY AND EFFECTIVENESS FACTORS

Now, it so happens that for the Mercury mission, as you have heard it outlined, namely, the altitude, the period of orbit, and the time in orbit, our factors involved in crew safety and effectiveness logically divide themselves into two groups of factors.

First, those which we term critical factors—the dynamic forces, the life support system, and the medical monitoring; and what we term the uncritical factors for this mission—weightlessness, isolation and confinement, and cosmic radiation.

You will immediately perceive that our so-called uncritical factors are what have been popularly termed the great mystery of manned space flight, and to a certain extent this is true, because none of these are capable of full duplication, apart from experiencing actual orbital flight.

On the other hand, as I will explain, there is nothing about these so-called intrinsic space factors that we do not know that we feel is critical to these first flights.

FORCES IMPOSED UPON HUMAN BEING IN ATTAINING ORBITAL VELOCITY

Let me examine briefly these critical factors and we will take up the dynamic forces which have been explained to the committee before.

These are mainly those forces imposed upon the human by the vehicle itself in attaining orbital velocity, and again when those forces

destroy this kind of kinetic energy in order that the vehicle can come in and make a safe landing.

As you all know, the services have been long interested in the question of dynamic forces as a part of our problem of getting people out of high-performance aircraft and protecting them on impact at crash landings. So we have a large body of data not only on the G tolerances, but also on the methods of protecting people when the G tolerances exceed expected limits.

In this chart we have on the left all of the phases of the Mercury mission which have been described, both if everything goes well and if things begin coming apart, and we have a very accurate prediction of the G stresses to be encountered as against the established tolerances.

Now, to give you a little better understanding of this, we have superimposed all the curves which are really force time histories. In other words, how much force for how long a time, and the peak.

We have superimposed all of these curves for every phase of the Mercury mission against these well-established human tolerance values. These have been determined on such things as our Holloman track and our large centrifuges, and you can see from this chart that we are well within human tolerance levels.

Lastly, by human tolerance we very definitely mean that the individual can accept these forces with proper positioning and proper restraint, and that he will suffer no irrevocable damage from it. He may not be comfortable and he probably won't be, but he will be no worse for wear.

Turning to the life support system, this again is simply a matter of carrying a little piece of the earth's atmosphere up into the vacuum of space. In this area we are fortunate in that working with submarines, with oxygen systems in aircraft, with pressurized cabins, with our manned high balloon flights and such, we have developed and subjected to a fairly broad spectrum of tests that are similar to what will be experienced in the Mercury mission, all of the various components that give a man the basic requirements during the period of the orbital mission.

This means not only food, water, pressure, and oxygen, but maintenance of any potential noxious gases below the atomic level.

Now, a word about the margin of safety. As you have heard it described, present plans are for no more than a 24-hour mission. In the components of the capsule system itself, allowance has been made for at least 48 hours, so that we have a 100-percent margin of safety.

Now, let's go to the worst possible case where everything fails, and the pilot is completely without his sustaining atmosphere within the capsule. We can still handle this one, because with adequate warning, he can immediately flip closed the visor to his space suit, very similar to the one that Mr. Crossfield is wearing in the X–15, and he has 120 minutes in which he has full protection from loss of oxygen, and also adequate cooling, which is very important.

Since our orbital period is only 90 minutes, this means that we could bring him back down into the earth's atmosphere well within the allocated time.

The final factor in the critical category is what we call medical monitoring, and what this really means is that we want to carry out fairly continuous monitoring of the human component, that is, how

he is functioning. Also as a corollary, we want to know how well all of the components that supply him with his vitally needed materials, are functioning.

It so happens that here again we are fortunate in that practically all animal and human experiments require that we maintain a constant record of vital data, both for immediate observation so that we can discontinue the experiment if the health or well-being of the subject is threatened, or as a permanent record to go back to, and actually add new knowledge in terms of human behavior and performance.

By virtue of this background, and using the sensing and recording equipment in our chambers in our man-high flights, in our X–15 we have evolved a system which we think will satisfy these two criteria of safe flight, and will add something to our knowledge of how man can survive and function in space.

CERTAIN INTRINSIC SPACE FACTORS CANNOT BE DUPLICATED APART FROM ACTUAL ORBITAL FLIGHT

Lastly, and I will discuss these uncritical factors only briefly, because my colleague, Dr. Worf, is going to discuss all of these in terms of future biomedical programs. However, I don't want to give you an erroneous idea. We have not tested and will not test an individual for the full duration of weightlessness, until he actually goes into orbit, but as physiologists we have every reason to believe that there is no vital physiological functions which will be compromised by the extension of time over what we have worked upon.

Of course, Laika was in orbit for some 5 to 7 or possibly 10 days, and the data we have from the Russians indicates that she got along very well.

This is also true as regards cosmic radiation. We cannot yet duplicate the full spectrum on earth, but from all of the physical measurements we know that even if the pilot were up there for 48 hours he would have received about 45 milliroentgens, which is well within the AE tolerance dose.

Finally, on the psychological aspects, we have been doing a lot of investigation on isolation, confinement, physical reaction, and complete separation from all terrestrial things. This can't be duplicated in orbit, but from our simulators we are convinced that with proper training, the astronaut will not suffer from isolation and confinement.

In conclusion, I simply want to give you two sides of the picture. We in the biomedical side certainly don't underrate our problems as team members. On the other hand, we do feel that the solution of these problems, both from an engineering and human standpoint, are such that we will meet the criteria for adequate safety.

Thank you.

CURRENT BIOMEDICAL PROGRAMS

PROJECT MERCURY
FACTORS IN CREW SAFETY & EFFECTIVENESS

DYNAMIC FORCES (G)
- ROCKET SLEDS
- CENTRIFUGE
- EJECTION TOWERS
- SPIN TABLE

LIFE SUPPORT SYSTEM
- CAPSULE SIMULATOR
- MAN HIGH CAPSULE
- SUBMARINE
- PRESSURE SUITS

MEDICAL MONITORING
- MAN HIGH FLIGHTS
- X-15 PHYSIOLOGIC TELEMETRY
- BIOLOGIC SPACE EXPERIMENTS

WEIGHTLESSNESS
- PARABOLIC FLIGHT
- PARTIAL SIMULATION

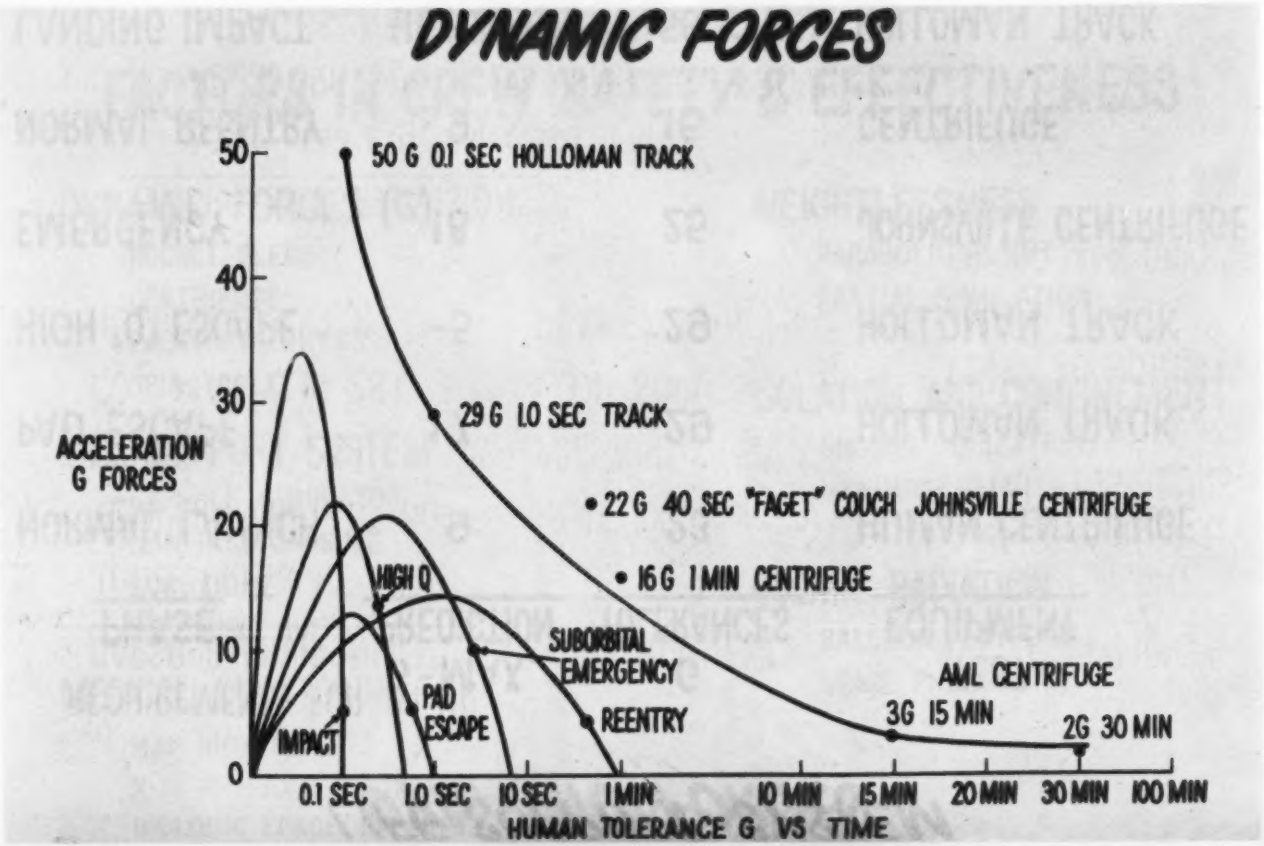
ISOLATION AND CONFINEMENT
- GROUND SIMULATION
- MAN HIGH FLIGHTS

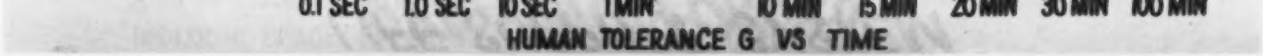
COSMIC RADIATION
- BALLOON PLATFORM
- SPACE PROBES

X-15 PHYSIOLOGIC TELEMETRY
BIOLOGIC SPACE EXPERIMENTS

DYNAMIC FORCES

PHASE	G-MAX. PREDICTION	G TOLERANCES	TEST EQUIPMENT
NORMAL LAUNCH	9	23	HUMAN CENTRIFUGE
PAD ESCAPE	17	29	HOLLOMAN TRACK
HIGH "Q" ESCAPE	-5	29	HOLLOMAN TRACK
EMERGENCY	18	25	JOHNSVILLE CENTRIFUGE
NORMAL REENTRY	9	16	CENTRIFUGE
LANDING IMPACT	16-22	50	HOLLOMAN TRACK


DYNAMIC FORCES
50 G 0.1 SEC HOLLOMAN TRACK
29 G 1.0 SEC TRACK
• 22 G 40 SEC "FAGET" COUCH JOHNSVILLE CENTRIFUGE
• 16 G 1 MIN CENTRIFUGE
ACCELERATION G FORCES
HIGH Q
SUBORBITAL EMERGENCY
AML CENTRIFUGE
3G 15 MIN
2G 30 MIN
PAD ESCAPE
REENTRY
IMPACT
50
40
30
20
10
0
0.1 SEC
1.0 SEC
10 SEC
1 MIN
10 MIN
15 MIN
20 MIN
30 MIN
100 MIN
HUMAN TOLERANCE G VS TIME



HUMAN TOLERANCE G VS TIME

LIFE SUPPORT SYSTEM

REQUIREMENTS FOR 24 HR CAPSULE ENVIRONMENT	COMPONENTS	TEST EQUIPMENT
TOTAL PRESSURE 5 P.S.I.	O_2 BOTTLES 3000 P.S.I.	MAN HIGH FLIGHT SINGLE - 32 HOURS TOTAL - 105 HOURS
TEMPERATURE 65°-80° F.	HEAT EXCHANGER	
OXYGEN --~4 P.S.I.	PRESSURE REGULATOR	ALTITUDE CHAMBER TEST - 48 HOURS
CO_2 MAX. 0.16 P.S.I.	L.OH SCRUBBER	
HUMIDITY ~0.2 P.S.I.	HEAT EXCHANGER	SUBMARINE 60×100 MAN DAYS

EMERGENCY PROVISIONS

100% MARGIN IN CAPSULE

PRESSURE SUIT - 120 MINUTES - PROVIDES O_2, PRESSURE, COOLING

MEDICAL MONITORING FOR CREW SAFETY

REQUIREMENTS	METHOD	TEST EQUIPMENT
CARDIO-PULMONARY FUNCTION	EKG RESPIROMETER O_2 RATE BLOOD PRESSURE	CHAMBERS MAN HIGH X-15/XF 102
PERFORMANCE	TASK RESPONSE	CHAMBERS-SIMULATORS
CONSCIOUSNESS	VOICE REPORTING TASK RESPONSE	ROCKET SLEDS
THERMAL	BODY AND CAPSULE THERMOCOUPLES	CENTRIFUGES
ENVIRONMENT	PRESSURE RECORDINGS TOTAL, O_2 REMAINING WATER VAPOR TENSION CO_2 DIFFERENTIAL	ANIMAL PROBES & SATELLITES

CO_2 DIFFERENTIAL

BIOMEDICAL FACTORS - SPACE ENVIRONMENT
(NOT CRITICAL TO CREW SAFETY)

CONDITION	TEST EXPERIENCE	DURATION	RESULTS
WEIGHTLESSNESS	AIRCRAFT - PARABOLIC FLIGHT PATH	20-80 SECS	NO EFFECT
	ANIMAL BALLISTIC	5-12 MIN	NO EFFECT
	LAIKA - ORBITAL	7-10 DAYS	NO EFFECT REPORTED
COSMIC RADIATIONS PRIMARY	HUMAN AND ANIMAL BALLOON	24-48 HRS	NO IMMEDIATE EFFECTS
	"PIONEER" MEASUREMENTS	45 MR/48 HRS	BELOW AEC TOLERANCE DOSE
PSYCHOLOGICAL ASPECTS (ISOLATION & CONFINEMENT)	VOLUNTEERS-SIMULATORS	5 DAYS	NO EFFECT
	MAN HIGH FLIGHTS	10-30 DAYS	NO EFFECT

Senator STENNIS. Well, it is an amazing statement. I have enjoyed it immensely.

General FLICKINGER. I didn't have any pretty pictures, though.

Senator STENNIS. Shall we hear someone else before we have a break for questions?

Mr. LOW. Dr. Worf, who is the next witness, will continue with the long-range biomedical programs.

Senator STENNIS. Come around, Doctor.

TESTIMONY OF DR. DOUGLAS L. WORF, CHIEF, BIOLOGY AND LIFE SUPPORT SYSTEMS, NASA

Dr. WORF. Thank you very much, Mr. Chairman.

My discussion will be on advanced medical programs. General Flickinger just spoke to you about the problems that we expect to experience in the short-term flights, such as Mercury.

In my discussion here I will try to stress the biological problems that we will get into when man is capable of occupying space, planets, or the Moon, for prolonged periods.

BIOMEDICAL CONSIDERATIONS—LONG-TERM FLIGHTS

One of the most challenging problems is to supply the man with adequate nourishment, oxygen, water, and clothing over these prolonged periods without unduly penalizing the usefulness of the mission.

Another problem that will arise in prolonged flights, at least one that we will have to anticipate and make provisions for, is chronic and acute toxicity. Man, himself, releases certain toxicants after a period of time. Carbondioxide is one. It is possible also that the materials inside the capsule, even the paint or perhaps a malfunction of the electronic components, might produce a toxicant material. This is something that we have to look into continually, all aspects of the materials of construction in the extended use of the capsule.

Sanitation is a problem, particularly in the weightless state, how are we going to handle human wastes so that the man will not become toxic and a hazard to himself in a space capsule?

Regarding the radiation problem, General Flickinger briefly discussed this for the short-term flight and stressed that this does not appear to be a problem. I will go into the aspects of radiation for extended manned space flight, in more detail later. The sources of radiation that man will be exposed to are cosmic radiation, the trapped radiation in the great radiation belt; you probably have heard discussions on this earlier, I will elaborate on it from the standpoint of hazard to man. Eventually it is expected that man will utilize nuclear components either for power or propulsion, and provisions must be made to protect him from this manmade nuclear radiation.

Physiological stresses—this is not intended to be complete—but I have listed several stresses that will have to be considered by the biomedical community.

Temperature, high temperature during reentry into Earth's atmosphere, entry into planets atmospheres or high and low temperature in long flights, say between the Earth and the Moon or Mars is a con-

sideration that the engineers and biologists must take into account in the design of a space capsule.

Weightlessness is a problem that is unique to space. Here again General Flickinger noted that weightlessness doesn't appear to be a serious handicap for short-term manned flights, but it is quite possible that physiological changes in the man will occur in prolonged, extended flights.

Psychological problems may turn out to be the real concern in prolonged flights. The fear of an initial launching, the psychological problems pertaining to extended flight when we have several people in a cramped capsule. Disorientation and isolation problems are also to be considered in the psychological aspects of space flight.

MANNED ORBITING SPACE LABORATORIES

This chart gives the future plans for placing man in space and in manned orbiting space laboratories. The detailed talks given earlier dealt with the Mercury type booster vehicle which is capable of putting about 2,500 pounds in space in a 150-mile orbit. In several years, we anticipate placing two men in space for a 2-weeks period. Then we will get into a still more advanced design, phase three, which will permit several men to be placed in an orbit for several weeks. This will be accomplished by a cluster of the Mercury type vehicle.

Finally, we get into the development of a very large vehicle, permitting a permanent space station to be placed in orbit containing half a dozen scientists or engineers to be placed in space, enabling them to make observations on technological, scientific and biological observations over a prolonged period of time.

One of the most challenging problems, as I mentioned earlier, is to keep man adequately supplied with food, and to keep him alive and well.

FOOD, OXYGEN, WATER REQUIREMENTS

The chart I have here shows the daily metabolic turnover of a man weighing about 154 pounds. He requires about 2 pounds of oxygen per day; about 5 pounds of water, and a little over a pound of solid food. That is his input. His output would consist of about 2 pounds of carbon dioxide, about 6 pounds of water, and just a small amount of solids, urea, and minerals.

It becomes obvious, by using a little arithmetic that man is going to eat the equivalent of his weight in about 20 days. In less than a year, he will have consumed about a ton of oxygen, food, and water. This gets to be prohibitive in terms of permissible payload to carry adequate food supplies along. So we will have to resort to utilizing some of this output for developing an input. In other words, we will have to regenerate some of the human waste. We would like to avoid this if at all possible, and are trying to develop every possible idea to extend the period of time where we will not have to regenerate any part of the human waste for food.

FOOD REGENERATION

This curve here shows the pounds of food required over this period of time of flight for one man. No regeneration is required of human

waste. Now, in order to extend this line beyond this 4-week breakoff period where we will have to begin at least the partial regeneration of human waste, we are looking into various chemicals and methods for extending this period of time.

One method would be to utilize potassium superoxide. This is a chemical which has the interesting characteristic of absorbing the carbon dioxide exhaled by man at the same time releasing oxygen. We also might look into such radical ideas as developing and utilizing some of the structural components of the capsule itself as edible material. This will not extend the nonregenerative period much beyond 4 to 6 weeks, however, after which we will have to consider the possibility of utilizing some human output for replenishing input requirements.

The water of elimination appears to be one of the first that we will work with by the selective use of ion exchange resins. It is anticipated that we can make the water potable or perhaps use it for dehydrated foods. This will extend the flight period to about 3 months, at which time we are going to have to consider a completely regenerative system, that is, one utilizing all human wastes.

COMPLETE FOOD, OXYGEN, WATER REGENERATION

This chart illustrates one suggestion for undertaking this procedure. We have here a cycling system where man's wastes are used for food by what we call an algal system. This algal system not only uses certain human wastes, the CO_2, the carbondioxide, and certain organic solids, but also requires solar radiation for its growth.

As algae grows, they release oxygen, and this is, of course, one of the requirements of man. Also, the algae themselves provide a nourishing food with the essential amino acids, protein, and carbohydrates requirements.

Therefore, this is one area that we are looking into very seriously, and perhaps in about 5 years, if our program progresses as we expect, we will have a prototype of a completely closed system available for testing in space.

Some of the problems we expect to investigate in space by the use of this system is the effect of radiation on these algae. If radiation causes a bad mutation, it might very well kill off the algal system. If this should occur while man is in orbit between the Earth and Mars, this, of course, would be fatal. Temperature also affects their growth, so we have to select an algal system very carefully.

RADIATION HAZARDS

Another problem that I mentioned to you just a moment ago is the radiation to which the pilot may be exposed. Such radiation affects unicellular organism algae, which I have here in this test tube. This radiation not only affects these algae system, causing mutations, but, as you well know, radiation affects man, too, especially ionizing radiation, as opposed to ultraviolet, which is regarded as one of the nonionizing radiations.

The most severe situation we have to face is the so-called great radiation belt discovered by Van Allen in his experiments with Pioneer III and earlier experiments with Explorer.

It appears now that this will not be a serious bottleneck to man's space flight, but it is another parameter we must consider. It will certainly not be a problem with the earlier Mercury flights, since they will be well below the point at which the first belt begins, about 1,500 miles above the Earth.

We can select most of our missions to orbit below that potentially hazardous region, or we can select them so that they will be between these belts where there is less radiation.

I will not attempt to go into detail regarding this chart on the great radiation belt. I think you have had an earlier presentation on these radiation belts, but I want to bring out a few points on how we are considering this radiation insofar as future manned space flights are concerned.

It is possible also that in the escape velocity the pilot would go directly through this belt without harmful radiation. We expect it would take about a half hour at this speed to get through the belts. Assuming that the charged particles are electrons, the pilot would get only about 5 rem per hour. This is the amount of radiation which is allowed per plant worker per year by the Atomic Energy Commission.

Of course, if they are protons, the pilot would get considerably more. He would get 50 rem, or 10 times that amount; but again, this is not regarded as a permanent physiologically damaging dose but this amount would certainly not be permitted for the world population. This so-called permissible level for you and me and the world at large is only 0.3 of a rem per year. The lethal dose for 50 percent of exposed persons (L.D. 50) is 450 rem, and if a passenger in these belts was unshielded for a period of 4½ hours, assuming charged particles are protons, he would receive L.D.–50. It would require several days to receive this L.D.–50 dose if corpuscular radiation were electrons.

The amount of shielding required, by the way, is about an inch of this plastic or about a half inch of aluminum to protect him indefinitely if he is in these belts.

WEIGHTLESSNESS

Now, another problem that we have to consider is living under a weightless condition. General Flickinger spoke to you about the fact that this is not regarded as a hazard for short-term flights. For long-term flights we anticipate certain problems. It will be an annoying situation to say the least. A man will have to develop new techniques for just getting around and performing useful functions. He will be required to develop new ways of walking, handling himself, and getting around.

In a weightless state the feeding problem is difficult, especially with liquids. Since liquids will not weigh anything, the pilot will have to use a special squirt bottle to get liquids into his mouth. He will probably not eat solid chunks of meat because this is apt to cause regurgitation and choking which could be fatal. So that in the weightless condition, the pilot may be required to use highly nutritious semifluids.

39621 O—59—pt. 1——25

Storage and handling have to be considered; dispensing liquids, as mentioned; sanitation; and we will have to develop esthetic accessory equipment for handling and disposing of human wastes.

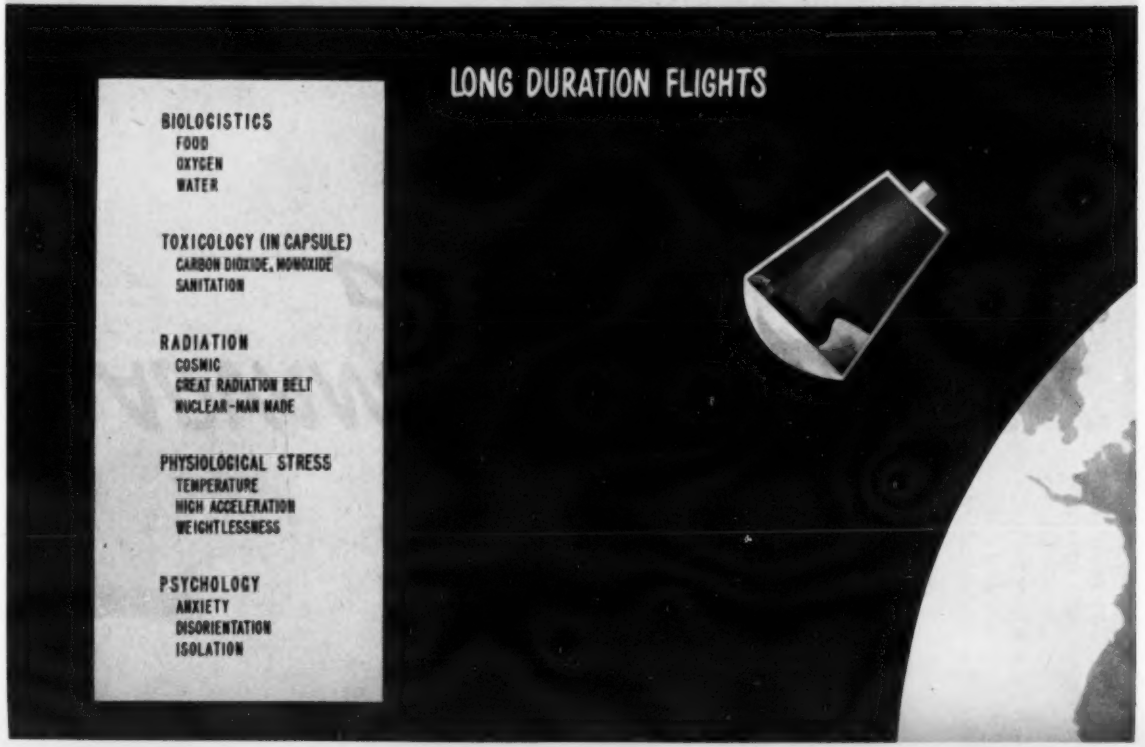
One of the ways for circumventing the problems in a weightless state would be to apply to the vehicle and its passengers an artificial or a simulated gravity. This is simply accomplished by rotating the vehicle. We can control the gravitational force to the required amount in this fashion.

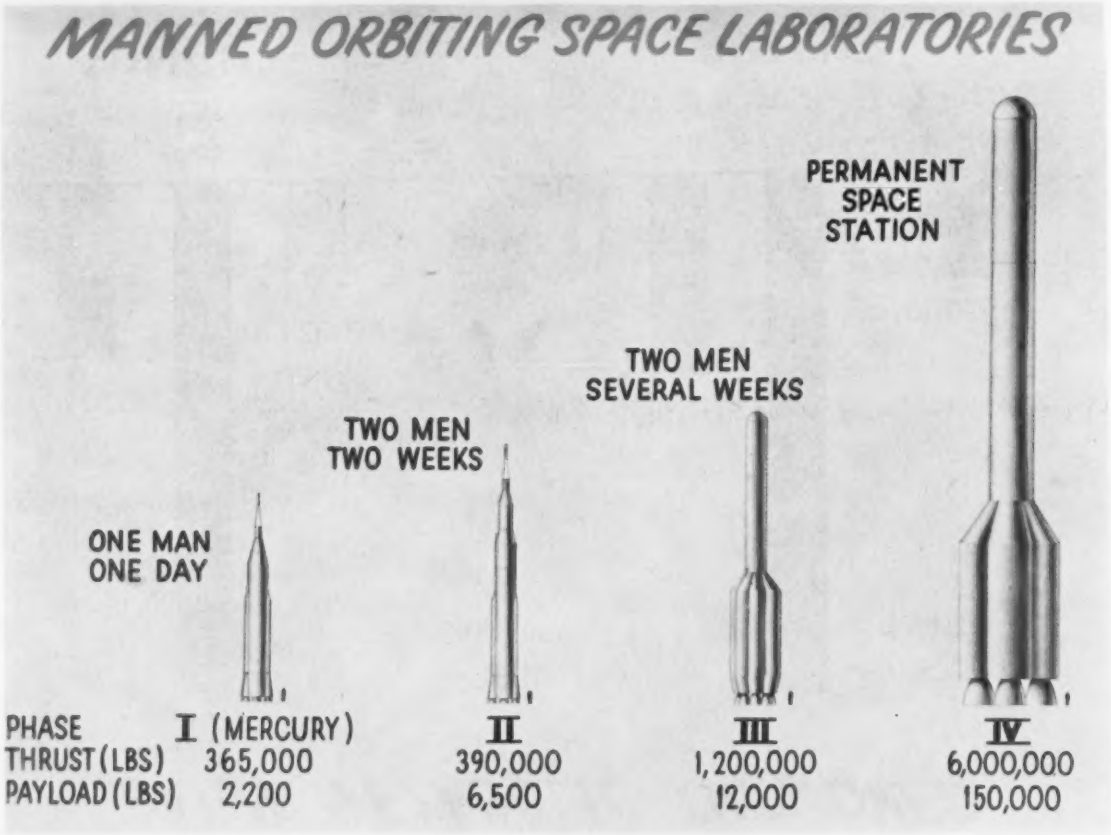
Well, I have not attempted here to give you the full picture of the problems that we are facing with long-term flight. I think that our main objective here, I can state in summary, is to make space life at least tolerable for man.

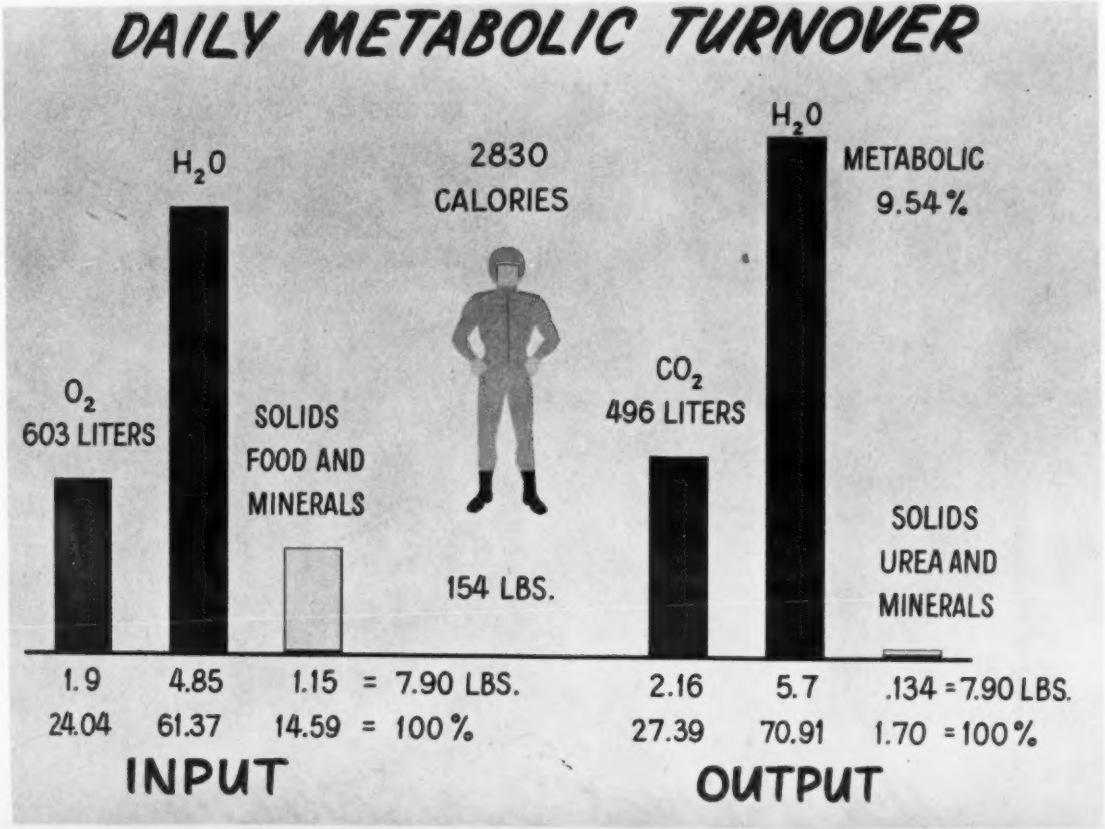
Thank you very much.

ADVANCED BIOMEDICAL PROGRAMS

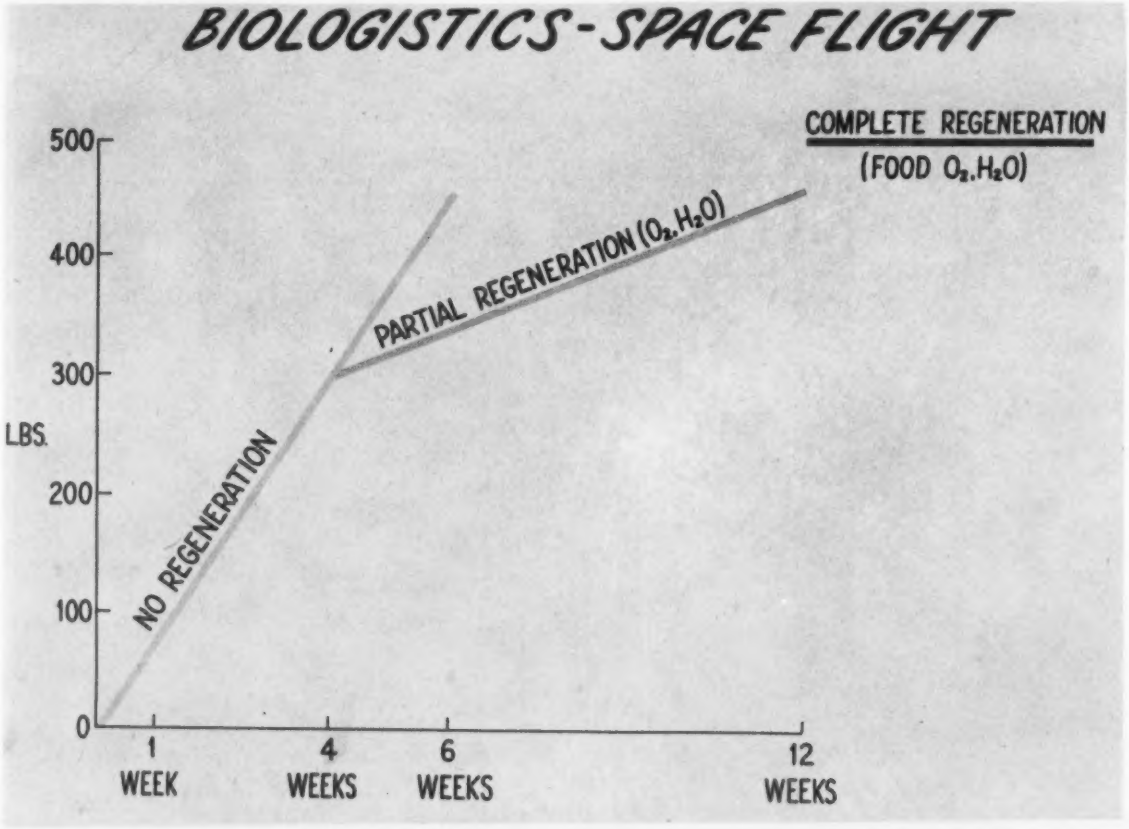
BIO-MED CONSIDERATIONS



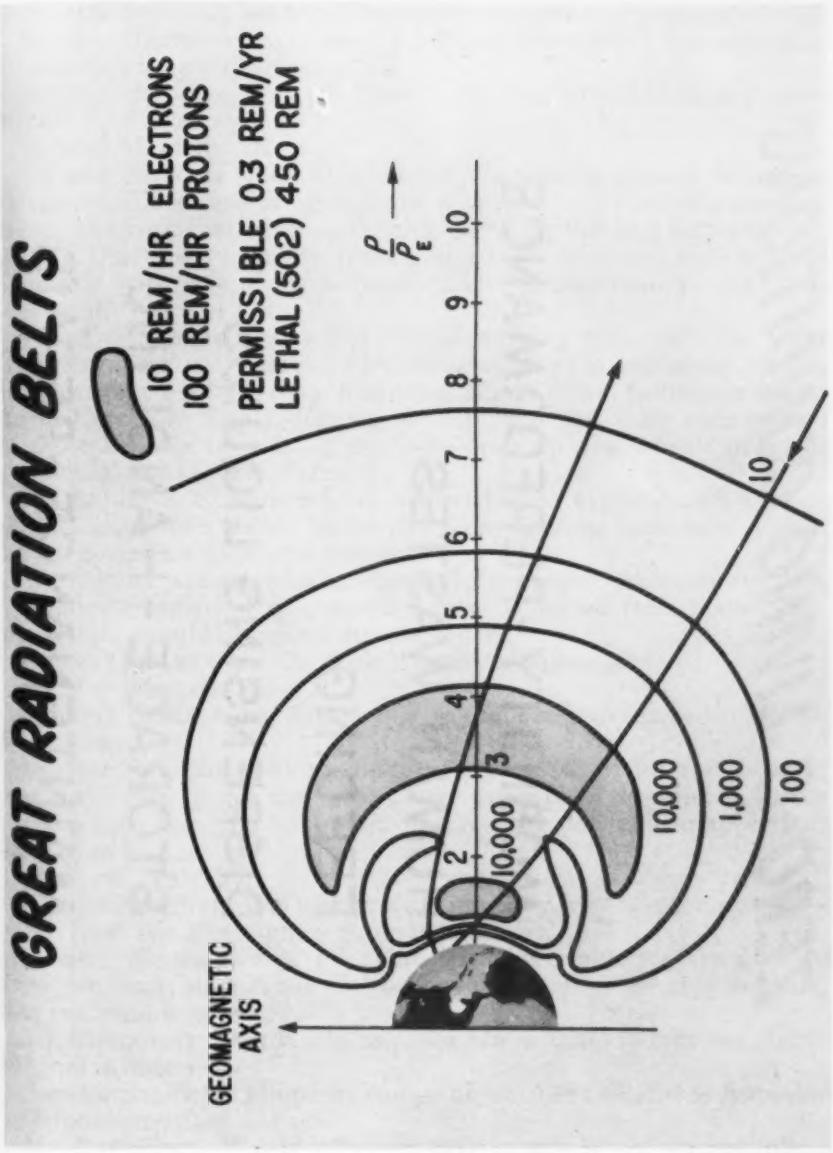

MANNED ORBITING SPACE LABORATORIES
ONE MAN
ONE DAY
TWO MEN
TWO WEEKS
TWO MEN
SEVERAL WEEKS
PERMANENT
SPACE
STATION
PHASE I (MERCURY) II III IV
THRUST (LBS) 365,000 390,000 1,200,000 6,000,000
PAYLOAD (LBS) 2,200 6,500 12,000 150,000


DAILY METABOLIC TURNOVER
H_2O
2830 CALORIES
H_2O
METABOLIC 9.54%
O_2 603 LITERS
SOLIDS FOOD AND MINERALS
154 LBS.
CO_2 496 LITERS
SOLIDS UREA AND MINERALS
1.9 4.85 1.15 = 7.90 LBS.
24.04 61.37 14.59 = 100%
2.16 5.7 .134 = 7.90 LBS.
27.39 70.91 1.70 = 100%
INPUT
OUTPUT

OUTPUT


BIOLOGISTICS - SPACE FLIGHT
COMPLETE REGENERATION
(FOOD O_2.H_2O)
PARTIAL REGENERATION (O_2.H_2O)
NO REGENERATION
LBS.
500
400
300
200
100
0
1 WEEK
4 WEEKS
6 WEEKS
12 WEEKS

PHOTOSYNTHESIS-REGENERATE FOOD, OXYGEN
ALGAL SYSTEM GENERATE FOOD O_2
FOOD, O_2
CO_2
ORGANIC SOLIDS CONVERTER
NON CO_2 WASTE
H_2O
WATER ELIMINATION


GREAT RADIATION BELTS
10 REM/HR ELECTRONS
100 REM/HR PROTONS
PERMISSIBLE 0.3 REM/YR
LETHAL (502) 450 REM
GEOMAGNETIC AXIS
ρ/ρE
2
3
4
5
6
7
8
9
10
10,000
10,000
1,000
100
10

ZERO-G LIVING CONDITIONS

MOBILITY - PERFORMANCE

HUMAN WASTES

FEEDING

DISPENSING LIQUIDS

STORAGE - HANDLING

MAINTENANCE - REPAIR

Senator STENNIS. That is a very good statement, indeed, sir.

Mr. LOW. This completes our discussions on manned space flight, Mr. Chairman.

Senator STENNIS. Senator Smith, do you have any questions?

Senator SMITH. I have many questions, but I won't ask any questions at this time. Thank you.

Senator STENNIS. Senator Martin, did you wish to ask any questions?

Senator MARTIN. No.

Senator STENNIS. Well, this is a very impressive presentation, gentlemen, and it is reassuring to know what progress you have made on it and the care that is being considered. It gives us a better appreciation that these men are truly going to be pioneers, and you believe you will have a manned space flight earlier than you are predicting it.

I was thinking there as you were describing those vehicles, I got into the reproduction of one of Columbus' ships in Barcelona, Spain, last year, but I believe these men are going to dwarf Columbus in history. Certainly they are going to help open up—these men as well as those helping to make it possible—open up new worlds in scientific affairs and human affairs.

Mr. Lehrer asks, with reference to radiation exposure, whether or not the same man would be barred from making successive flights, should he make a successful first one?

Mr. LOW. I wonder whether General Flickinger would answer that.

Senator STENNIS. I say, would a man be barred from making another flight should he make a successful one?

General FLICKINGER. On these Mercury missions, sir?

Senator STENNIS. Yes.

General FLICKINGER. No, sir, he would not have exceeded his allowable dose.

Senator STENNIS. I think there will be a lot of interest here, if you could give us for the record later a complete description of the various tests that you have used in screening down these applicants from 55 to 7.

Mr. LOW. Yes, sir.

Senator STENNIS. You may proceed now.

Mr. LOW. Mr. Cortright is going to take over.

Senator STENNIS. Yes, all right, Mr. Cortright, we are glad to have you back, sir. What do you have on your mind this morning that you want to present?

Mr. CORTRIGHT. It will take us just a few minutes to take our charts out, and in order——

Senator STENNIS. I hope we can go on until 12:30, if it is agreeable with the committee.

Mr. CORTRIGHT. Would it be agreeable to you, sir, if we just take a moment or two to get the charts rearranged?

Senator STENNIS. Oh, yes, get your charts out and we will take a little break here for a few minutes while you are taking out your charts.

(A short recess was taken.)

Senator STENNIS. All right. I understand the gentlemen are ready to proceed now.

If we may have order, please. Proceed, sir, in your own way.

Mr. CORTRIGHT. Thank you.

You have now been exposed to the general scientific programs which we hope to undertake, and some of the more interesting and exciting applications such as the meteorological and communications applications, and now finally the manned space flight program. In addition you have heard on the first day the propulsion requirements to undertake these programs.

Now we come to a little more mundane area but one which is extremely important, and that is the development of advanced components and techniques. In general, to undertake all of the more glamorous programs which you have heard about, there must be a broad base of advanced technology developed in other areas. In these next six talks we are going to select some of them, some of the more interesting and understandable ones, and discuss them for you.

The first talk will be concerned with guidance. Now, guidance, of course, is a vital element of any space mission. If we drive from here to the White House and miss a turn, all we have to do is go around the block. But on a space mission, we have to perform to near perfection. Orbital-type flight and flight between planets is a very unforgiving mode of travel. We simply can't afford to carry with us sufficient propulsion to correct very many errors, or very large errors.

The first talk now will be concerned with insertion or injection guidance, that part of the guidance which takes place in the first part of a flight. This talk will be delivered by Mr. John P. Clayborne, assistant to the Head of the Guidance and Control Division at the Army Ballistic Missile Agency.

Senator STENNIS. All right, Mr. Clayborne, we are glad to have you here, sir.

TESTIMONY OF JOHN P. CLAYBORNE, TECHNICAL ASSISTANT TO THE DIRECTOR, GUIDANCE AND CONTROL LABORATORY, ARMY BALLISTIC MISSILE AGENCY, HUNTSVILLE, ALA.

Mr. CLAYBORNE. As Mr. Cortright mentioned, I am concentrating on insertion guidance, and I would like to define that term a little bit.

Most of the satellites, as a matter of fact all of the satellites that have been put in orbit, have been guided during the early booster stages, or during the first few minutes of flight, and at the termination of the last thrust stage they were said to be inserted or injected into orbit, so it is the accuracy with which you guide the vehicle up to this injection point that determines what the orbit will be.

Now we use this term to differentiate this type of guidance from midcourse and terminal guidance which are involved in more advanced missions, such as interplanetary flight.

I won't dwell on those two phases other than to state they do require additional propulsion means and, therefore, if you can accomplish a mission with simple injection guidance, it will usually be cheaper to do so. This turns out to be the case for most satellite missions. So let's examine the effects of guidance accuracy on the type of orbit that you will achieve.

INJECTION ACCURACY FOR EARTH ORBITS

Shown on the left is a circular orbit achieved by injecting a satellite, in this case a 220-mile altitude, in a perfectly horizontal direction and with this exact velocity. If you accomplish that at the injection point when all your thrust is cut off, you will then have the circular orbit shown. Of course, in the early attempts to place satellites in orbit, allowance was made for errors and additional velocity was usually planned.

Here we see a measure of the effect of this excess velocity. With slightly over 1,000 miles excess velocity, which you see is an error in velocity, or an excess of velocity of several percent, you will then get an orbit that looks about like this. Actually, several of the satellites placed in orbit had about this shape of trajectory. So you see this is not too critical. You can aim for 500 miles an hour excess velocity, and if you get it, and you get more than that, you will still wind up somewhere between these two orbits, both of which are useful for many purposes.

Now we will have some missions where it will be desirable to get a higher orbit than we have been able to achieve to date. As was pointed out earlier, wherever you cut off is the altitude that you will return to when the satellite goes around once. So a technique has been evolved for achieving these higher orbits, and you probably will hear more of this technique in the future, it is sometimes called a kick in the apogee.

The technique here amounts to placing a satellite in an elliptical orbit in the usual fashion by injection at this point. But then if we wait until it is exactly halfway around the Earth and have reserved ourselves a little bit of propulsive energy here and we give it a kick, it will then take the orbit shown in red instead of returning to the original perigee.

One possible use for this technique would be for the NASA aluminum sphere or a similar satellite, which are very light in density, and you need to put them higher if they are to have a useful life in orbit. This method doesn't require any drastically increased guidance requirements, but it does get you there in a cheaper fashion.

There will be, of course, a need for more accurately determined orbits than those which we have been content with to date when we are measuring radiation, and we sometimes like to have a lopsided orbit so that we scoop up more altitudes in our measurements, but for meteorological satellites we might like to have one nearly circular. This calls for a little increase in guidance accuracy.

We were talking here of a few percent in the velocity, that is, the accuracy with which we establish velocity. When we talk about nearly circular orbits we are down to one-tenth of 1 percent in accuracy.

I neglected to say anything about the accuracy with which you approach the horizontal injection point, but the effects are rather complicated. But for the simple elliptical orbits we try to hit within two or three degrees. We will have to go down to tenths of degrees in the new generation of satellites coming up.

24-HOUR ORBIT

I am going to dwell in a little more detail on a rather interesting satellite, the 24-hour satellite. This, as you have probably heard, is the satellite which is placed in orbit at such a distance that it will circle the Earth every 24 hours. If it is on the Equator it will appear to be stationary overhead. The Earth is not to scale on this picture, but it is shown that three such satellites provide point-to-point communications by relaying signals among them to any spot on Earth.

Let's look at a way that you might put a 24-hour satellite into orbit. The Earth is drawn to scale here; I believe this gives you a little better perspective on the height of this orbit. If you recall the earlier one, it looks as though the satellites are almost on top of the Earth, and those are to scale for orbits we have achieved.

This one is 22,000 miles up. It would be or it could be—there are, of course, different ways of accomplishing these missions, but it could be injected in the usual manner into what would be a very lopsided ellipse if you did nothing further. With the figures that you compute as necessary for this mission, you have a 5- to 6-hour coast period during which it coasts out to a distance of 22,000 miles.

Now the injection accuracy requirements are still another order of magnitude more difficult here. We are now talking of holding the angle at which we inject to one-tenth of a degree or less, and the velocity has to be accurate to about 1 one-hundredth of 1 percent. This is to say we are talking about an injection velocity of 23,000 miles per hour and we want to know it to 1 or 2 miles per hour. This is really precise measurement, obviously.

With injection and coasting over a 5- to 6-hour period, the satellite will have slowed down from its 23,000 miles an hour to about 3,500. Now, at this altitude, to achieve a 24-hour orbit it needs to have a speed of about 7,000, so it has only got about half of what it needs, and the kick rocket has to supply the other half. Again, it has to be supplied very precisely in a very accurately determined direction and magnitude.

Now the best that you can do in injection guidance will allow you to put it in position within a few miles, but it might have drifts of the order of 1 degree per day as seen from down on Earth. Well, this won't do; in a year it would go all around the Earth, and it wouldn't be a stationary satellite. So there will need to be final, very small velocity corrections which may be made after perhaps several days of tracking. What we would like to shoot for is 1 degree a year, and this is quite a challenge; but it is by no means impossible as an objective.

One more word on the rendezvous satellite. It approaches in accuracy the requirements of the 24-hour satellite. A rendezvous satellite might be one that you would use to send up supplies to an orbiting vehicle. The first requirement is to match the orbit of the vehicle which you want to approach, and you can, with injection guidance; you can pretty well match the orbit and bring it up close to the other satellite. Then you will need some sort of terminal guidance to home it on.

Satellites have been placed in orbit using different types of guidance, and I would like to say a few words on the principles of these guidance systems.

PRINCIPLES OF GUIDANCE SYSTEMS

The primary categories are the radio guidance systems, or the inertial guidance systems that have been used for injection guidance to date. I think the radio guidance is clear to most everyone, inasmuch as it uses radar to track the missile, and we are familiar with radar tracking.

Of course, there are several functions here. It must find out where the missile is and know at all times during its ascent. Then it must compare this known position and velocity with where the missile should be, and then it must generate a direction. These latter functions are performed by computers, of course, and the first sending is done with radar in the radio case.

The inertial guidance system seems to be cloaked with a certain amount of mystery, and I would like to bring in a simple analogy here with the hope it will clear up its operating principles a little bit.

Inertial guidance is completely self-contained, doesn't rely on any external information, and it operates on the same forces of inertia as you feel as you accelerate your car rapidly. Of course, it throws you back into your seat. This force is measurable and I think the easiest way of seeing how it could be measured is to use this analogy.

Suppose you have a spring scale just like a fishing scale and you can hang a 1-pound weight from it. The pointer will, of course, remain on the 1-pound mark as long as you are holding the scale steady, but if you accelerate upward, the inertial of the weight will cause it to extend the spring and the pointer will indicate something greater than 1 pound.

Now the excess weight that is indicated here is an exact measure of the acceleration that you have used and if you know this excess weight or this acceleration and the time over which it has acted, this is all that you need to know to compute how far you have gone, how fast you are going at the end of that period. I don't know whether that is clear or not, but that is the essence of the inertial guidance system.

Here is where we get complicated. There are, of course, three directions in space, so of course you have to have three of these accelerometers. Secondly, if you want an accelerometer also to measure in one direction, for example, if you want your accelerometer to measure all of your acceleration in that direction, you have got to keep it pointed, but your missile may be rolling or pitching or making various motions, so the stable platform which you probably heard of comes into the picture, and this is nothing but a mounting base for the accelerometer that is linked to the missile with bearings so that the missile can roll about this platform or pitch about it and the platform stays pointing in the same direction in space.

How is this done? It is done by placing gyroscopes on the platform which sense any tendency to upset it, and they provide signals for keeping it righted.

That is a pretty hasty picture of an inertial platform, and I can't dwell too much on the hardware because—well, you can't do the job with fishing scales as you can see here.

This is a type of gyro stabilizer or platform, and in this case this ring-shaped structure is the structure that is held fixed in space. On it

are mounted, here we see two gyroscopes in cutaway. These are the gyroscopes that sense any tendency to upset the platform, and in the other cams here are the accelerometers which will always point in their designated direction in space.

Well, signals from these accelerometers sent to a computer will tell you from inside the vehicle, and you can put one of these in your automobile and it will tell you just how far you had gone, if you had the whole system there, without ever looking out. These signals fed to a computer give you all of this information. Now both systems have been successfully used in the satellites put up to date, and both will continue to be used, and they both can possess a high degree of accuracy.

GUIDANCE CAPABILITIES

I would like to review briefly the accuracies for the different types of missions and mention what capability there must be to achieve these.

The first type was that simple elliptical orbit of the type that most satellites that have flown would come into this category. We need two or three degrees angular accuracy, several hundred miles appear as several percent velocity accuracy. Obviously, since they have been flown, these requirements have been met.

The second category is the type of slightly more advanced satellite where altitude requirements must be kept within more confined limits or for the more nearly circular-orbit satellite, and we have to go down to fractions of a degree, and now we are in the tens of miles per hour in which to control that velocity, whereas we were in the hundreds.

The 24-hour satellite, and the rendezvous satellite, require angular accuracies in the tenths of a degree and velocity control to one part in several thousand. This capability we have; I would like to qualify my statements on our capability in these two areas for this reason: Our satellites to date have all been capable of handling very small payloads. As you know, the Explorers and Vanguards have about a 20-pound capability.

Now to give precise guidance to a satellite you would like to fly the guidance equipment in the last stage, if it is a three-stage vehicle; you would like to carry this guidance equipment right up to the last moment so that it would be guiding each stage in turn.

Because of our propulsion limitations that have led us to small payload capabilities, we can't do this, or we haven't been able to do this to date, and the guidance and control engineers have had to make several different types of compromises.

One compromise that has been used is to guide the first or booster stage only, and then let subsequent stages fly off unguided, and you just tolerate the amount of error that they may make which you cannot correct, and this is all right for putting a satellite in an elliptical orbit.

Another compromise that is being worked on is to design guidance systems lighter and lighter so that they can be put in these upper stages, and in the second category there are vehicles in advanced stages of development which do just this.

In the third category we do possess guidance capability to guide to these accuracies, but not with systems which are boosters which permit us to fly. That is to say, in the future, as our payload capabilities go up, we can put our best guidance systems in, we can

definitely accomplish these objectives, but right now we don't have the combination of booster capability and guidance accuracy to satisfy these objectives.

ATTITUDE CONTROL

I would just like to go briefly into spatial attitude control, which has been mentioned. If you are going to take a look at a star, you obviously want your vehicle to keep pointing that way in the direction of the stars; if you are going to take a look at something on earth, you have to be pointing toward earth all the time. You have no air vanes or anything to work out in space, so you have to have inertial means of controlling attitude. One that has been used and is in use for spatial attitude is the jet nozzle. By expelling material from one of these jets you will cause the vehicle to rotate that way or vice versa that way. A more advanced method uses a flywheel, just uses the reaction of turning the flywheel on, of spinning the vehicle. This can be powered with solar cells, and thereby for long missions it has more promise.

I would like to throw in the comment here that if artificial gravity is required, that is an attitude control problem, too. We may have to spin the living quarters to provide gravity, or even if it isn't required we may have to stabilize the living quarters so that one man, in taking a step, won't turn things around or he won't get along very well with his fellow travelers if he disturbs their equilibrium too often.

RESEARCH AND DEVELOPMENT AREAS

Just in conclusion here are some areas where further research seems to be indicated. These attitude control systems which I mentioned, I won't say anything more about, attitude sensors. We always have to have some reference; we don't know which way is up in a satellite unless we can look at the earth or sun, or something. And gravity gradient, there is a slight difference in gravity in different parts of the satellite which we may be able to employ.

Star trackers—that is evident. Long life components—most of them function for only a few months. We don't know what will happen if we have to let them function for years, and we need to investigate that. The same applies to reliability with hundreds of thousands of components, and as man gets into space the need for reliability is even greater, so our guidance investigations are pretty basic in these fields.

For the future we have hopes in the science of cryogenics, low temperature phenomena which holds promise for almost frictionless bearings which allows them to run for a year. Of course, communications are going up by leaps and bounds, and even more effort is required here in order to use radio links for guidance. As you know, we reached out 400,000 miles now, and that is a mighty good start. Miniaturization will also be important because guidance equipment competes with payload, and the more you can miniaturize the more payload you can put in.

I believe that concludes my presentation.

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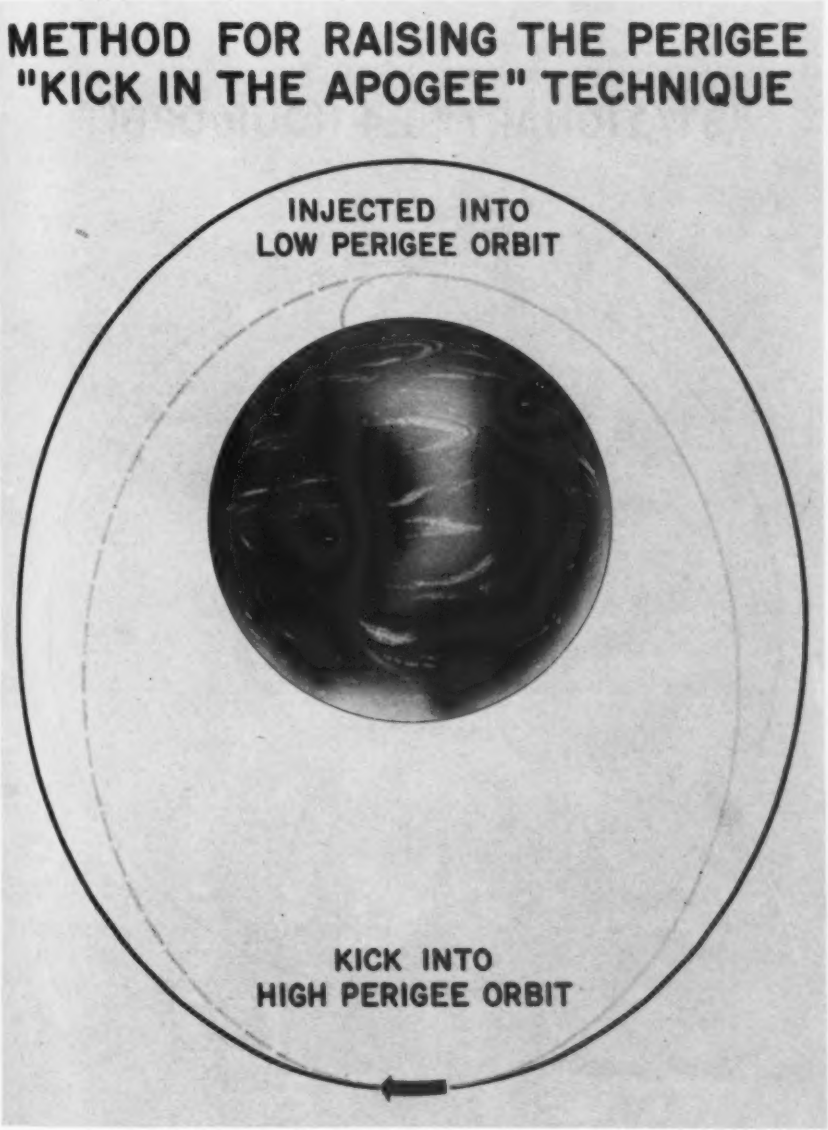
INSERTION GUIDANCE FOR SATELLITES

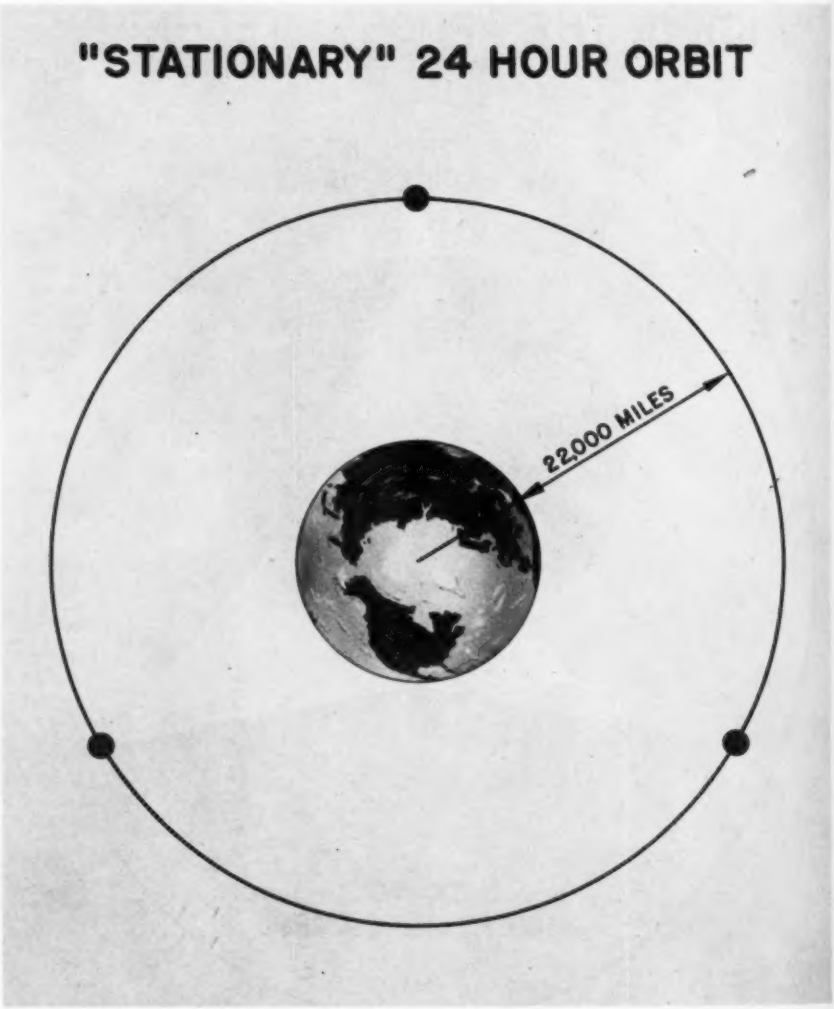
EARTH ORBITS EFFECT OF INJECTION ACCURACY

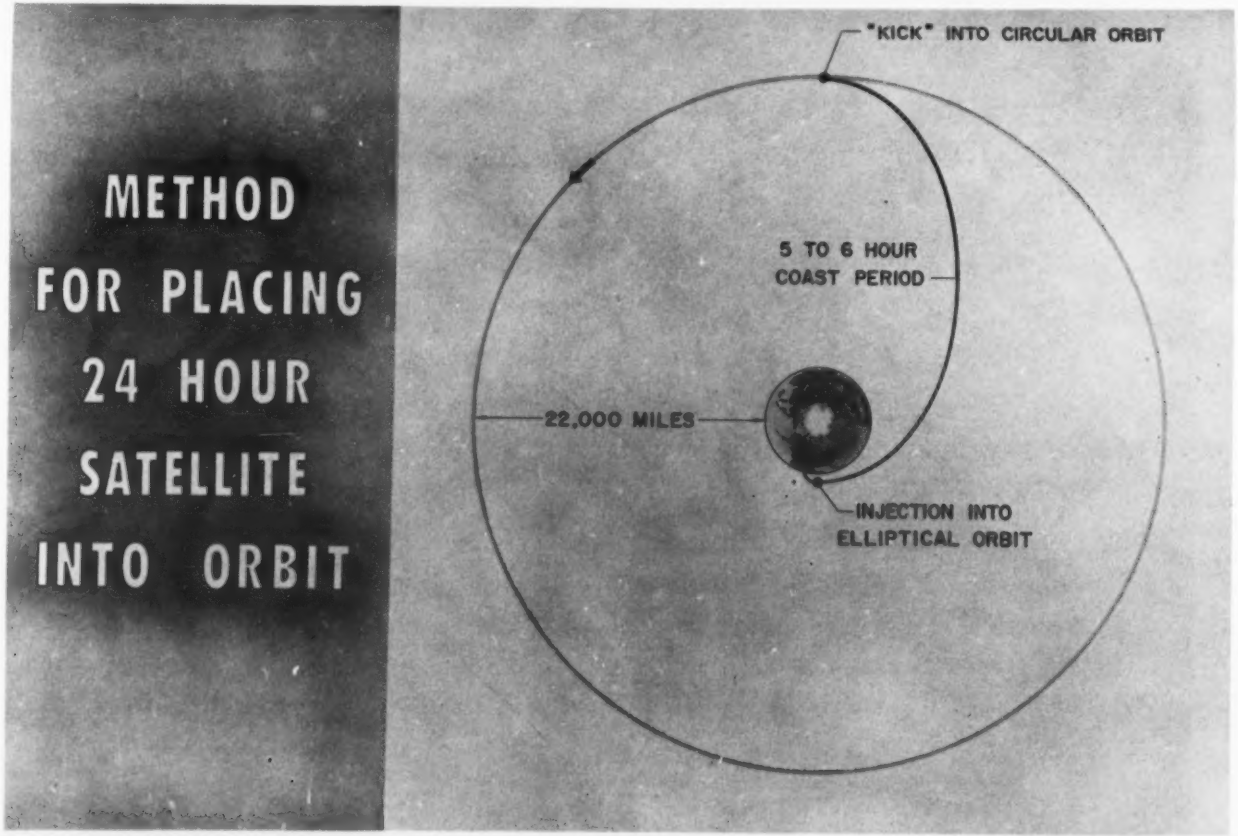
CIRCULAR ORBIT AT 220 MILES
VELOCITY=17,300 MPH

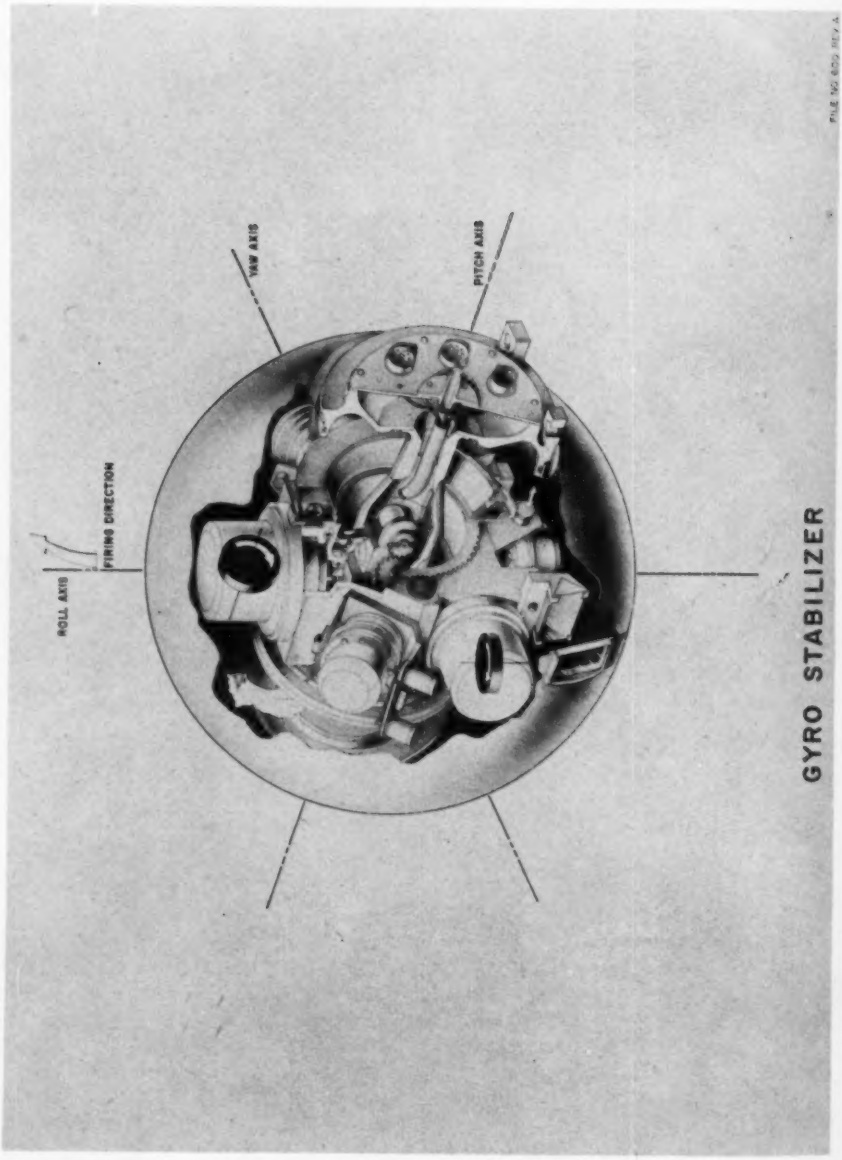
ELLIPTICAL ORBIT
VELOCITY=18,350 MPH
(1050 OVER CIRCULAR)



(1050 OVER CIRCULAR)


"STATIONARY" 24 HOUR ORBIT
22,000 MILES

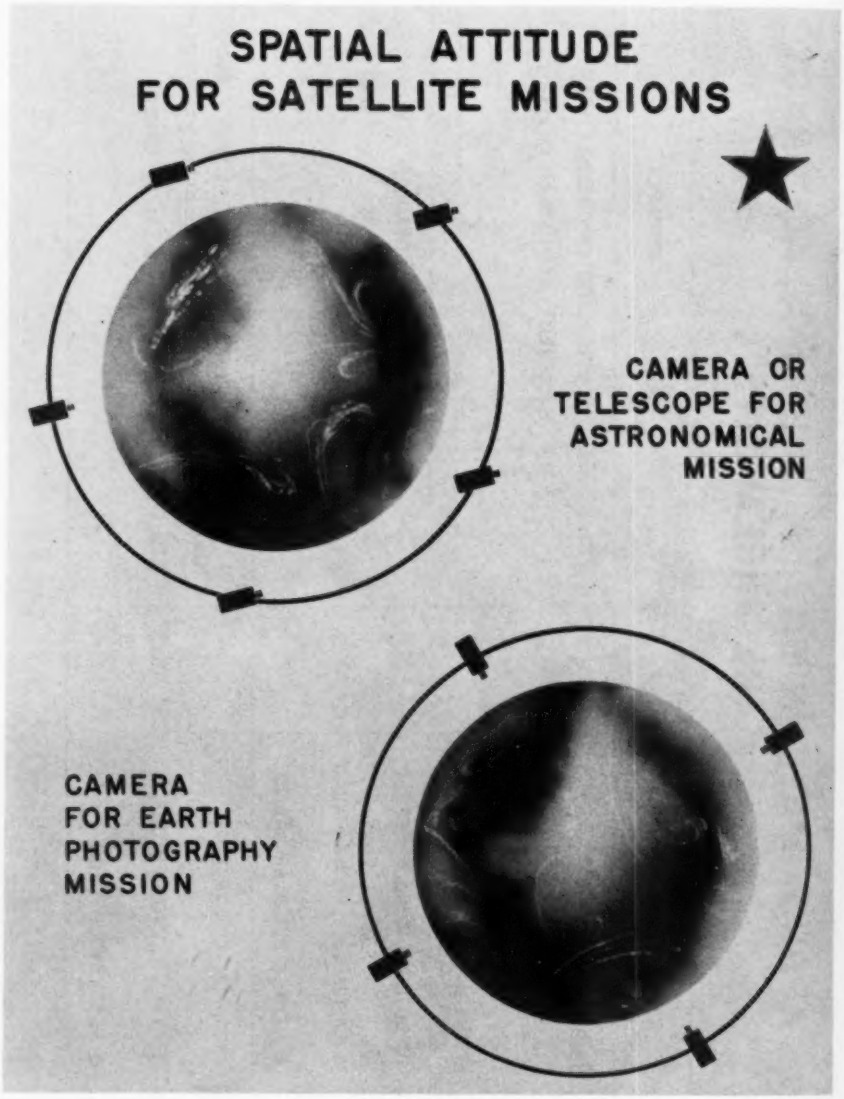

METHOD
FOR PLACING
24 HOUR
SATELLITE
INTO ORBIT
"KICK" INTO CIRCULAR ORBIT
5 TO 6 HOUR
COAST PERIOD
22,000 MILES
INJECTION INTO
ELLIPTICAL ORBIT

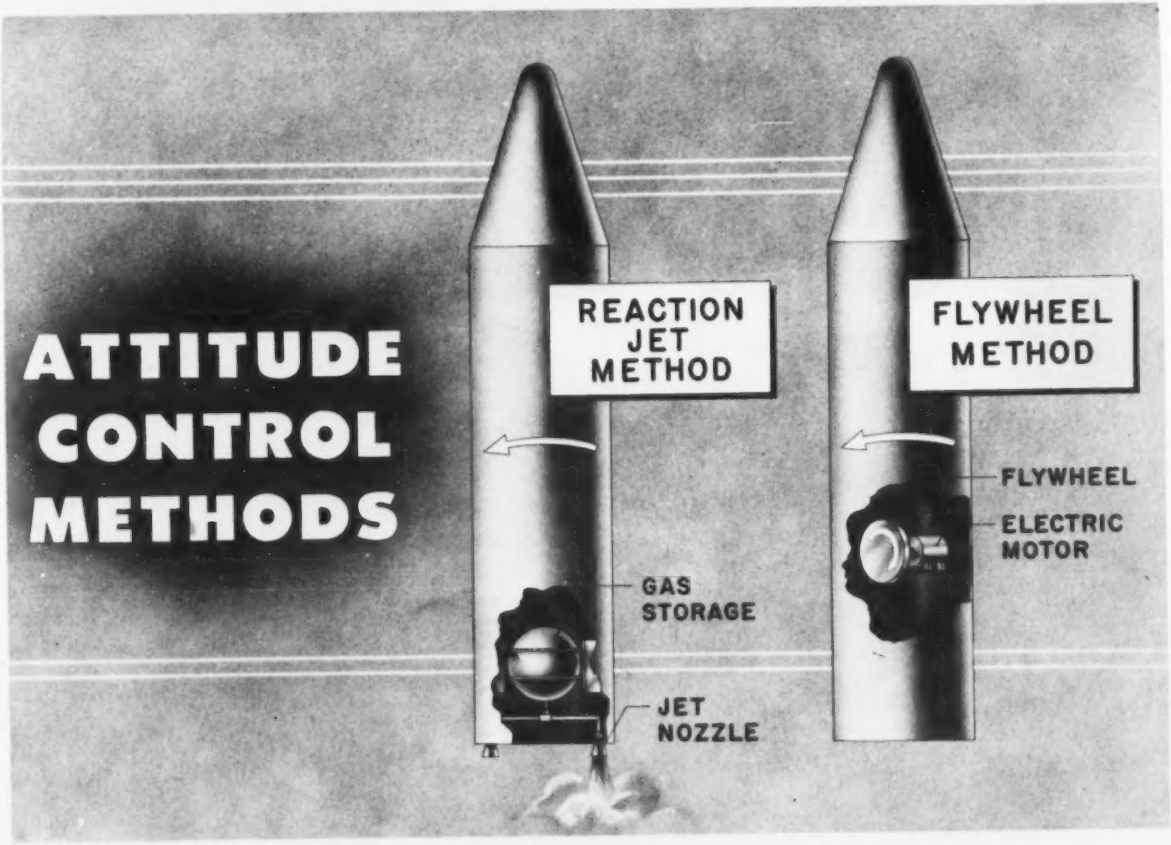

YAW AXIS
PITCH AXIS
ROLL AXIS
FIRING DIRECTION
GYRO STABILIZER

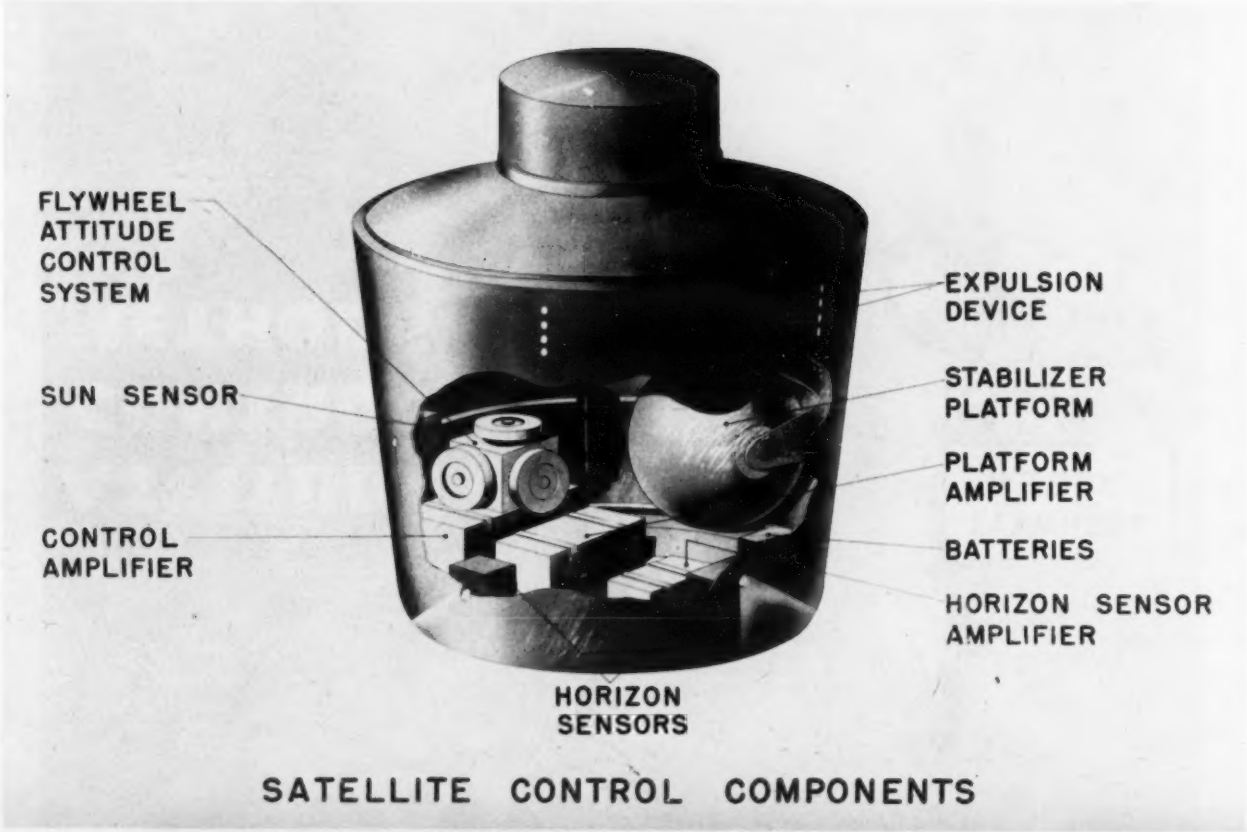
APPROXIMATE INJECTION GUIDANCE ACCURACY REQUIREMENTS

TYPES OF MISSIONS	ALLOWABLE ERROR AT INJECTION		REMARKS
	ANGLE (DEGREES)	SPEED (M.P.H.)	
I MINIMUM GUIDANCE ACCURACY A. SIMPLE ELLIPTICAL ORBITS B. MINIMUM ALTITUDE	2° TO 3°	100 TO 500mph	REQUIREMENTS CAN BE MET WITH EQUIPMENT AVAILABLE.
II. IMPROVED ACCURACY NEEDED A. SPECIFIC ELLIPTICAL ORBITS B. NEARLY CIRCULAR ORBITS	1/2° TO 2°	25 TO 50 mph	EQUIPMENT IN ADVANCED DEVELOPMENT STAGES WILL SATISFY REQUIREMENTS.
III. PRECISION GUIDANCE A. 24 HOUR CIRCULAR ORBIT B. RENDEZVOUS ORBIT	.1° TO .25°	1 TO 2 mph	PRECISION GUIDANCE IN UPPER STAGES REQUIRED. ALSO SUPPLEMENTARY RADIO LINKS OR TERMINAL GUIDANCE.

FIGURE 6


SPATIAL ATTITUDE
FOR SATELLITE MISSIONS
CAMERA OR
TELESCOPE FOR
ASTRONOMICAL
MISSION
CAMERA
FOR EARTH
PHOTOGRAPHY
MISSION


ATTITUDE CONTROL METHODS
REACTION JET METHOD
FLYWHEEL METHOD
FLYWHEEL
ELECTRIC MOTOR
GAS STORAGE
JET NOZZLE



SATELLITE CONTROL COMPONENTS

SATELLITE CONTROL COMPONENTS

RESEARCH AND DEVELOPMENT AREAS FOR ADVANCED GUIDANCE & CONTROL SYSTEMS

1. ATTITUDE CONTROL SYSTEMS
2. ATTITUDE SENSORS
   - A. HORIZON SEEKERS, GRAVITY GRADIENT SENSORS
   - B. STAR TRACKERS
3. LONG LIFETIME COMPONENTS
4. RELIABILITY INVESTIGATIONS
5. ADVANCED DEVELOPMENTS IN CRYOGENICS, RADIO COMMUNICATIONS, MINIATURIZATION

FIGURE 10

Senator STENNIS. We thank you very much. Are there any questions?

(No response.)

Senator STENNIS. I don't know that I had ever heard of any explanation of this before. You haven't had this in your briefing before, have you?

Mr. CORTRIGHT. No, this is the first.

Senator STENNIS. Senator Martin, do you have any questions?

If not, we thank you very much. You have another witness in this category, do you not?

Mr. CORTRIGHT. Yes, sir, we do.

Senator MARTIN. Is that inertial guidance system more accurate than one you can feed in by a computer sending messages to the missile? Can you compare them?

Mr. CLAYBORNE. That is a question that can't be answered simply, sir. I think theoretically you can achieve the accuracies with either systems that we need for the missions we have considered to date. But I don't believe we could discuss detailed ramifications of this here.

Mr. CORTRIGHT. Mr. Chairman, I might mention that we do have a very few typical components of a guidance system which we will leave open for you, if you have time.

Senator STENNIS. All right. Mr. Cortright, it will be all right for those gentlemen who have made their presentattions to leave, although we would be glad to have them return after the recess. I thought some of them might be from out of town and might be wanting to return home.

Mr. CORTRIGHT. Thank you.

Senator STENNIS. All right, the committee will take a recess then until 2 o'clock.

(Whereupon, at 12:40 p.m., the subcommittee recessed, to reconvene at 2 p.m., this same day.)

AFTERNOON SESSION

Senator STENNIS. Let's come to order please. It might be a matter of interest to those that are here—NASA has sent us the names of the young men we referred to this morning; the astronauts for project Mercury. We will read their names.

Malcolm S. Carpenter, a lieutenant in the U.S. Navy.

Leroy G. Cooper, Jr., a captain in the U.S. Air Force.

John H. Glenn, Jr., a lieutenant colonel in the U.S. Marine Corps.

Virgil I. Grissom, a captain in the U.S. Air Force.

Walter M. Schirra, Jr., a lieutenant commander in the U.S. Navy.

Alan B. Shepard, Jr., a lieutenant commander in the U.S. Navy.

Donald K. Slayton, a captain in the U.S. Air Force.

(A background statement on the selection of astronauts for project Mercury follows, together with biographical sketches of the astronauts selected.)

PROJECT MERCURY ASTRONAUT SELECTION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

BACKGROUND

Many of the conditions expected in orbital space flight are similar to those experienced by military test pilots. NASA, therefore, went to this field to seek

volunteers for the Mercury astronaut training program. More than 100 military test pilots meet the general qualifications; of these, 69 were interviewed in Washington, D.C., and 80 percent volunteered to proceed. Personal consultations and interviews followed, and the list of candidates was narrowed to 32.

In this initial phase, and in the following selection steps, evaluation was extremely difficult because of the high caliber and motivation of the candidates. During the course of the selection program it was determined that seven is the optimum number of Mercury astronauts so that each can have full participation in all phases of the Mercury development.

PHYSICAL FITNESS

Immediately following their Washington interviews the candidates were assigned to groups, five of six men each and one of two. One group at a time reported to the Lovelace Clinic in Albuquerque, N. Mex., for an exhaustive series of examinations. The other men returned to their home stations to await the call for their groups. The first contingent entered Lovelace February 7, and the others on succeeding Saturdays. Each candidate spent 7½ days and 3 evenings at the Lovelace facility.

General physical requirements were established by the NASA Life Sciences Committee; since all those examined are active test pilots it was not anticipated that any would be disqualified as physically unfit. Rather, degrees of physical soundness were obtained and evaluation was dependent upon a comparison of each man to his fellow candidates.

To establish a comparative yardstick, the Lovelace program began with a complete aviation and medical history and extended to these areas:

Hematology and pathology (blood and study of tissues).
Roentgenology (X-ray consultations).
Ophthalmology (eyes).
Otolaryngology (ears, nose, and throat).
Cardiology (heart and circulation).
Neurology and myology (nerves and muscles).
General internal medicine.
Related laboratory studies.

Special consultations were provided if indicated by the candidate's medical history or any of the general examinations. These examinations were given under normal clinical procedures, while the subject was in a resting condition. To assess the candidate's abilities under load, Lovelace physicians developed a series of dynamic tests which were used for the first time in the Project Mercury selection process.

Capacity underload, or body efficiency, was determined from a correlation of the subject's physical competence with his pulmonary function, total body radiation count, specific gravity of the body, blood volume, water volume, lean body mass, and detection of tiny congenital openings between the chambers of the heart.

Results of the static and dynamic tests were recorded on special computing cards developed by the Lovelace Clinic for the astronaut program. These cards are mark-sensed so they may be read directly by the examining physician and contain the candidate's complete aviation and medical histories and examination findings.

PSYCHOLOGICAL AND STRESS EVALUATION

The next step in the selection process was a minute determination of the candidate's psychological makeup and an estimate of his ability to cope with stresses expected in space flight.

Basis for this part of the selection took into consideration previously developed studies made in anticipation of the need for a program to select and precondition pilots for extreme high altitude flights. The program was tailored to meet the specific requirements foreseen for orbital flight.

The Air Force, with the assistance of Army and Navy specialists, conducted psychological and stress measurements at the Wright Air Development Center Aeromedical Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio. The examinations were in these general areas:

Personality evaluation
Behavioral sciences
Stress and fatigue
Accelerative forces
Equilibrium and vibration
High energy noise
Low barometric pressure
Thermal stress
Anthropology

Testing at WADC was conducted with candidates in six groups of five men each and one group of two. The first group entered February 15; each man was evaluated 6 days and 3 evenings.

A complex appraisal of both clinical and statistical test results went into the WADC evaluation of candidates. As in the case of the Lovelace examinations, results were not a matter of passing or failing, but instead were measures of how one candidate compared with all others.

Because manned satellite flight is without precedent, Mercury astronauts will be pioneers not only in space flight but also in the development of a program which will determine qualities best suited for such special missions.

FINAL SELECTION

Data from the Lovelace and WADC examinations were compiled and forwarded to the NASA Space Flight Activity, Langley Field, near Hampton, Va., for the fourth and final step in the selection process. At Langley, a group representing both the medical and technical fields evaluated the previous examinations. The seven ultimately selected were chosen as a result of physical, psychological and stress tolerance abilities and because of the particular scientific disciple, or specialty, each represents.

CLINICAL EXAMINATIONS GIVEN BY THE LOVELACE CLINIC

Medical history and physical examination including internal examinations and orthopedic or other specialty consultations as indicated.

Laboratory tests: Hemoglobin (measure of oxygen carrying red pigment); hematocrit (examination of blood by use of a centrifuge); grouping; Rh factor; serology (examination of blood serums); sedimentation rate (analysis of urine deposits); stool examinations; urinalysis; gastric analysis; cholesterol (substance present in gallstones, heart ailments, etc.); liver function test; urinary steroid excretion (measure of the hormones, acids and poisons); blood nitrogen; blood protein; protein-bound iodine; special serum studies; throat culture, and chemical examination of body outputs, and blood counts.

X-rays: Chest, large intestine, sinuses, spine, stomach, esophagus, teeth and heart. Moving pictures were taken of the heart to determine any artery calcification.

Eyes: History, dilation, visual fields, tonometry (measure of inner pressure on the eyes), slit lamp, dynamic visual acuity, depth perception, night vision, and photography of conjunctival vessel (eye membrane), and retina.

Ears, nose and throat: Examination of throat and nasal passages; audiogram with and without background noises; speech discrimination and voice tape recording.

Heart: Cardiograms of heart muscle contraction, heart stroke volume and heart sounds; measure of the chest which overlies the heart.

Nerves and muscles: General neurologic examination with muscle testing; electric stimulation of the nerves to determine response; measure of any nerve abnormality; tracing of electric currents produced by the brain.

SPECIAL DYNAMIC EXAMINATIONS GIVEN BY THE LOVELACE CLINIC TO MEASURE BODY EFFICIENCY

Physical competence: Measured by an ergometer, a device similar to a bicycle. Subject pedals increasing amount of weight while wearing an oxygen mask. Heartbeat and oxygen consumption determined. Evaluation is made by the amount subject can pedal by the time his heart reaches 180 beats per minute.

Pulmonary function: Lung capacity and breathing efficiency determined by measuring the amount of oxygen subject breathes normally and during exercise.

Lean body mass, a correlation of the following: Total body radiation count, conducted by the Atomic Energy Commission Los Alamos Laboratories to determine the amount of potassium in the body; specific gravity, weighing the subject in air and while he is totally immersed in water; blood volume, measured by inhaling a small amount of carbon monoxide and observing the amount absorbed by the blood after a specified time; water volume, determined by swallowing a small amount of tritium and observing its rate of dilution.

Presence of the heart chamber openings: Amount of blood oxygen is measured during and after a Valsalva maneuver. The Valsalva exercise is accomplished by blocking the nose and blowing into a tube.

STRESS TESTS CONDUCTED AT THE WRIGHT AIR DEVELOPMENT CENTER

Harvard step: Subject steps 20 inches to a platform once every 2 seconds for 5 minutes to measure his physical fitness.

Treadmill maximum workload: Subject walks at a constant rate on a moving platform which is elevated 1° each minute. Test continues until heart reaches 180 beats per minute. Test of physical fitness.

Cold pressor: Subject plunges his feet into a tub of ice water. Pulse and blood pressure measured before and during test.

Complex behavior simulator: A panel with 12 signals, each requiring a different response. Measure of ability to react reliably under confusing situations.

Tilt table: Subject lays on steeply inclined table for 25 minutes to measure ability of the heart to compensate for body in an unusual position for an extended time.

Partial pressure suit: Subject is taken in pressure chamber to a simulated altitude of 65,000 feet in an MC1 partial pressure suit. Test lasts 1 hour. Measure of efficiency of heart system and breathing at low ambient pressures.

Isolation: Subject goes into a dark, soundproof room for 3 hours to determine his ability to adapt to unusual circumstances and to cope with the absence of external stimuli.

Acceleration: Subject is placed in a centrifuge with his seat inclined at various angles to measure his ability to withstand multiple gravity forces.

Heat: Subject spends 2 hours in a chamber with the temperature at 130° F. to measure reaction of heart and body functions while under this stress.

Equilibrium and vibration: Subject is seated on a chair which rotates simultaneously on two axes. He is required to maintain the chair on an even keel by means of a control stick with and without vibration, normally and while blindfolded.

Noise: Subject is exposed to a variety of sound frequencies to determine his susceptibility to tones of high frequency.

PSYCHOLOGICAL TESTS ADMINISTERED BY WRIGHT AIR DEVELOPMENT CENTER

To determine personality and motivation: Interviews; Rorschach (ink blot); apperception (tell stories suggested by pictures); draw-a-person; sentence completion; self-inventory based on 566-item questionnaire; officer effectiveness inventory; personal preference schedule based on 225 pairs of self-descriptive statements; personal inventory based on 20 pairs of self-descriptive statements; preference evaluation based on 52 statements; determination of authoritarian attitudes, and interpretation of the question, "Who am I?"

To determine intelligence and special aptitudes: Wechsler adult scale; Miller analogies; Raven matrices; Doppelt mathematical reasoning test; engineering analogies; mechanical comprehension; officer qualification test, aviation qualification test; space memory; spatial orientation; hidden figures perception; spatial visualization, and peer ratings.

MEMBERS OF NASA LIFE SCIENCES COMMITTEE

Chairman, Dr. W. Randolph Lovelace II, director of the Lovelace Foundation for Medical Education and Research, Albuquerque, N. Mex.; members: Capt. Norman L. Barr (MC), Director, Astronautical Division, Navy Bureau of Medicine and Surgery, Washington, D.C.; Lt. Comdr. John H. Ebersole (MC), medical officer, U.S.S. *Seawolf*, Fleet Post Office, New York, N.Y.; Brig. Gen. Donald D. Flickinger (MC), Surgeon and Assistant Deputy Commander for Research, Headquarters, Air Research and Development Command, Washington, D.C.; Lt. Col. Robert H. Holmes (MC), Chief of Biophysics and Astronautics Branch, Army Medical Research and Development Command, Washington, D.C.; Dr. Wright H. Langham, Los Alamos Scientific Laboratory, University of California; Dr. Robert B. Livingston, Director of Basic Research in Mental Health and Neurological Diseases, National Institutes of Health, Bethesda, Md.; and Dr. Orr Reynolds, Director of Science, Office of the Assistant Secretary of Defense for Research and Engineering, Washington, D.C. Boyd C. Myers II, NASA Headquarters, is secretary of the committee.

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ASTRONAUTS SELECTED FOR PROJECT MERCURY

MALCOLM SCOTT CARPENTER, PROJECT MERCURY ASTRONAUT

Malcolm S. Carpenter, a lieutenant in the U.S. Navy, was born May 1, 1925, in Boulder, Colo. He now lives at 11911 Timmy Lane, Garden Grove, Calif. His mother is living in Boulder at 5335 Broadway. Carpenter's father, a retired chemist, lives in Palmer Lake, Colo. His wife is the former Rene Louise Price, whose parents, Mr. and Mrs. Lyle S. Price, live at 963 Ninth Street, Boulder. The Carpenters have four children: Mark Scott, 9; Robyn Jay, 7; Kristen Elaine, 3; and Candace Noxon, 2. Carpenter is 5 feet 10½ inches tall, weighs 160 pounds, and has green eyes and brown hair.

After receiving his early education through high school in Boulder, Carpenter entered Colorado College in 1943 to participate in the V–5 flight training program sponsored by the U.S. Navy. After a year there, he spent 6 months in training at St. Mary's preflight school, Moraga, Calif., and 4 months in primary flight training at Ottumwa, Iowa. When the V–5 program ended at the close of World War II, Carpenter entered the Univrsity of Colorado to major in aeronautical engineering. He received a degree there in 1949.

Following his graduation, Carpenter joined the Navy and received flight training from November 1949 to April 1951 at Pensacola, Fla., and Corpus Christi, Tex. He spent 3 months in the Fleet Airborne Electronics Training School, San Diego, Calif., and, until October 1951, in a Lockheed P2V transitional training unit at Whidbey Island, Wash.

In November 1951, he was assigned to Patrol Squadron 6 based at Barbers Point, Hawaii. During the Korean conflict, he was engaged with Patrol Squadron 6 in antisubmarine patrol, shipping surveillance, and aerial mining activities in the Yellow Sea, South China Sea, and the Formosa Straits. In 1954 he entered the Navy Test Pilot School at the Naval Air Test Center, Patuxent River, Md., and after completion of his training was assigned to the electronics test division of the NATC. In this assignment Carpenter conducted flight test projects with the A3D, F11F, and F9F and assisted in other flight test programs. He then attended the Navy's General Line School at Monterey, Calif., for 10 months and the Naval Air Intelligence School, Washington, D.C., for a further 8 months. In August 1958, he was assigned to the U.S.S. *Hornet*, antisubmarine aircraft carrier, as air intelligence officer. He has accumulated more than 2,800 flying hours, including 300 in jet aircraft.

His hobbies include skin diving, archery, and water skiing.

LEROY GORDON COOPER, JR., PROJECT MERCURY ASTRONAUT

Leroy G. Cooper, Jr., a captain in the U.S. Air Force, was born March 6, 1927, in Shawnee, Okla. He is 5 feet, 9½ inches tall and weighs 150 pounds. The 32-year-old astronaut has blue eyes and brown hair. He considers as his hometown Carbondale, Colo., where his parents, Col. and Mrs. Leroy G. Cooper, have a ranch. Colonel Cooper is retired from the Air Force. His wife is the former Trudy Olson of Seattle, Wash. The couple has two daughters, Camala K., 10, and Janita L., 9.

Cooper attended primary and secondary schools in Shawnee, and he attended the University of Hawaii 3 years. He received a degree in aeronautical engineering through the Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio, in August 1956.

Cooper entered the Marine Corps in 1945 after his graduation from high school. He attended the Naval Academy Preparatory School and was a member of the Presidential Honor Guard in Washington immediately before his discharge in August 1946. While at the University of Hawaii, he received a commission in the Army. He transferred this commission to the Air Force and was recalled by that service for extended active duty in 1949 for flight training. After his training, he was assigned to the 86th Fighter Bomber Group in Munich, Germany, as an F–84, and later, as an F–86 pilot. After his graduation from AFIT, he was assigned to the Air Force Experimental Flight Test School at Edwards Air Force Base, Calif. He was graduated from this school in April 1957, and was assigned duty in the Performance Engineering Branch of the Flight Test Division at Edwards. He conducted flight test on experimental fighter aircraft. Cooper has 2,300 flying hours, including 1,400 in jets.

His hobbies are photography, riding, hunting, and fishing.

JOHN HERSCHEL GLENN, JR., PROJECT MERCURY ASTRONAUT

John H. Glenn, Jr., a lieutenant colonel in the U.S. Marine Corps, was born July 18, 1921, in Cambridge, Ohio. He considers New Concord, Ohio, his permanent home. He attended primary and high schools in New Concord, and Muskingum College. His parents are Mr. and Mrs. John H. Glenn. The elder Glenn is a retired operator of a plumbing and heating business. Mrs. Glenn is the former Anna Margaret Castor, daughter of Dr. and Mrs. H. W. Castor. The elder Glenns and Castors all live on Bloomfield Road in New Concord. The Glenns have two children: John David, 13, and Carolyn Ann, 12. Glenn also has a sister, Mrs. Jean Pinkston, of Cambridge. He is 5 feet 10½ inches tall, weighs 180 pounds, and has green eyes and red hair.

Glenn entered the naval aviation cadet program in March 1942. He was graduated and commissioned in the Marine Corps a year later. After advanced training, he joined Marine Fighter Squadron 155 and spent a year flying F4U fighters in the Marshall Islands. During his World War II service he flew 59 combat missions. After the war he was a member of Fighter Squadron 218 on North China patrol and had duty in Guam. From June 1948, to December 1950, he was an instructor in advance training at Corpus Christi, Tex. Glenn then attended Amphibious Warfare School at Quantico, Va. In Korea, he flew 63 missions with Marine Fighter Squadron 311 and 27 while an exchange pilot with the Air Force. In the last 9 days of fighting in Korea, he downed three Mig's in combat along the Yalu River. After Korea, Glenn attended test pilot school at the Naval Air Test Center, Patuxent River, Md. After graduation, he was project officer on a number of aircraft, including the F8U, F8U–1, and F8U–P. Since November 1956, he has been assigned to the Fighter Design Branch of the Navy Bureau of Aeronautics in Washington.

Glenn has been awarded the Distinguished Flying Cross on five occasions and he holds the Air Medal with 18 clusters for his service during World War II and Korea. In July 1957, while project officer of the F8U, he set a transcontinental speed record from Los Angeles to New York, spanning the country in 3 hours, 23 minutes. He has more than 5,000 hours of flying time, including 1,500 hours in jet aircraft. Glenn has been attending the University of Maryland during his Washington assignment.

The Glenn family hobbies are boating and water skiing.

VIRGIL IVAN GRISSOM, PROJECT MERCURY ASTRONAUT

Virgil I. Grissom, a captain in the U.S. Air Force, was born April 3, 1926, in Mitchell, Ind. Five feet, seven inches tall, he weighs 155 pounds and has brown eyes and brown hair. His parents, Mr. and Mrs. Dennis D. Grissom, live at 715 Baker Street, Mitchell. He has two brothers, Norman, of Mitchell, and Lowell, a sophomore at Indiana University, and a sister, Mrs. Joe Beavers of Baltimore. Mrs. Grissom is the former Betty L. Moore. Her father, Claude Moore, lives in Mitchell. Her mother is deceased. The Grissoms have two sons, Scott, 9, and Mark, 5.

Grissom attended primary and high schools in Mitchell and was graduated from Purdue University with a degree in mechanical engineering in 1950.

He first entered the Air Force in 1944 as an aviation cadet. He was discharged in November 1945. He returned to aviation cadet training after his graduation from Purdue, and he received his wings in March 1951. Grissom joined the 75th Fighter-Interceptor Squadron at Presque Isle, Maine, as an F–86 fighter pilot. He flew 100 combat missions in Korea in F–86's with the 334th Fighter Interceptor Squadron. He left Korea in June 1952 and became a pilot instructor at Bryan, Tex. In August 1955, he went to the Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio, to study aeronautical engineering. In October 1956 he attended test pilot school at Edwards Air Force Base, Calif., and returned to Wright-Patterson Air Force Base in May 1957, as a test pilot assigned to the fighter branch. He has flown more than 3,000 hours, over 2,000 in jets.

Grissom has been awarded the Distinguished Flying Cross and Air Medal with Cluster.

His hobbies are hunting and fishing.

WALTER MARTY SCHIRRA, JR., PROJECT MERCURY ASTRONAUT

Walter M. Schirra (Shi-RAH) Jr., a lieutenant commander in the U.S. Navy, was born March 12, 1923, in Hackensack, N.J. The 36-year-old astronaut is five feet, 10 inches tall, weighs 185 pounds, and has brown hair and brown eyes. His parents, Mr. and Mrs. Walter M. Schirra, reside in Honolulu, Hawaii, where the elder Schirra is a civil engineer with the Air Force. The senior Schirra was a World War I ace in the Army Air Corps. After the war, he and his wife barnstormed throughout the Eastern United States in a light plane. The astronaut's wife is the former Josephine C. Fraser of Seattle, Wash. The couple have two children: Walter III, 8, and Suzanne Karen, 1. Mrs. Schirra is the daughter of Mrs. James L. Holloway, wife of Admiral Holloway, who was commander-in-chief of the Northeastern Atlantic and Mediterranean area. Schirra also has a sister, Mrs. John H. Burhans, who lives in Patuxent River, Md.

Schirra attended primary and junior high schools in Oradell, N.J. He was graduated from Dwight Morrow High School, Englewood, N.J., in 1940, and attended Newark (N.J.) College of Engineering 1 year. He was graduated from the U.S. Naval Academy in 1945.

Schirra has had service on board the battle cruiser *Alaska*, the staff of the Seventh Fleet, flight training at Pensacola, in a Navy fighter squadron (71), and as an exchange pilot with the 154th U.S. Air Force Fighter Bomber Squadron. He went with this squadron to Korea where he flew 90 combat missions in F–84E aircraft. He downed one Mig and has one probable Mig. He took part in development of the Sidewinder missile at China Lake, Calif. He was project pilot for the F7U–3 Cutlass and instructor pilot for the Cutlass and FJ3 Fury. He flew F3H–2N Demons as operations officer of Fighter Squadron 124 on board the carrier *Lexington* in the Pacific. He then attended naval air safety officer school at the University of Southern California, and test pilot training at the Naval Air Test Center, Patuxent, Md. His last assignment was at Patuxent in suitability development work on the F4H. He has 3,000 hours of flying time, 1,700 hours in jets.

He has been awarded the Distinguished Flying Cross and two Air Medals for his Korean service.

ALAN BARTLETT SHEPARD, JR., PROJECT MERCURY ASTRONAUT

Alan B. Shepard, Jr., a lieutenant commander in the U.S. Navy, was born November 18, 1923, in East Derry, N.H. The 35-year-old astronaut is 5 feet, 11 inches tall, weighs 160 pounds, and has blue eyes and brown hair. His parents, Col. and Mrs. Alan B. Shepard, live in East Derry where the elder Shepard, a retired Army of the United States officer, is an insurance broker. Shepard is married to the former Louise Brewer of Kennett Square, Pa. The couple has two daughters, Juliana, 8, and Laura, 12. Shepard's sister, Mrs. Pauline S. Sherman, resides in Montclair, N.J.

Shepard attended primary school in East Derry and was graduated from Pinkerton School, Derry, N.H., in 1940. He studied 1 year at Admiral Farragut Academy, Toms River, N.J., and then entered the Naval Academy, Annapolis. He was graduated from Annapolis in 1944. He was graduated from the Naval War College, Newport, R.I., in 1958.

The astronaut saw service on the destroyer *Cosgrove*, in the Pacific during World War II. He then entered flying training at Corpus Christi, Tex., and Pensacola, Fla. He received his wings in March 1947. Subsequent service was in Fighter Squadron 42 at the Norfolk Naval Air Station and Jacksonville, Fla. He also spent several tours in the Mediterranean. Shepard went to test pilot school at Patuxent River, Md., and served two tours in flight test there. During this service, he took part in high altitude tests to obtain data on light at different altitudes and in a variety of air masses over the North American continent. He also took part in experiments in test and development of the Navy's in-flight refueling system; carrier suitability trials of the F2H3 Banshee, and Navy trials of the first angled carrier deck. Between his flight test tours at Patuxent, Shepard was assigned to Fighter Squadron 193 at Moffett Field, Calif., a night fighter unit flying Banshee jets. He was operations officer of this squadron and made two tours with it to the western Pacific on board the carrier *Oriskany*. He has been engaged in the test of the F3H Demon, F8U Crusader, F4D Skyray, and F11F Tigercat. He was project test pilot on the F5D Sky-

lancer. The last 5 months at Patuxent were spent as an instructor in the test pilot school. After his graduation from the Naval War College, Shepard joined the staff of the commander in chief, Atlantic Fleet, as aircraft readiness officer. He has 3,600 hours of flying time, 1,700 in jets.

Shepard's hobbies are golf, ice skating, and water skiing.

DONALD KENT SLAYTON, PROJECT MERCURY ASTRONAUT

Donald K. Slayton, a captain in the U.S. Air Force, was born March 1, 1924, in Sparta, Wis. The 35-year-old astronaut is 5 feet, 10½ inches tall, weighs 160 pounds and has blue eyes and brown hair. His parents, Mr. and Mrs. Charles S. Slayton, live in Sparta. A brother, Howard, and sister, Mrs. Lyndahel Hagen, also live in Sparta. Slayton's immediate family also includes a brother Richard, of San Jose, Calif.; another brother, Elwood, and two sisters, Mrs. Milton Madsen and Mrs. Harold Schluenz, all of Madison. His wife is the former Marjorie Lunney, daughter of Mr. and Mrs. George Lunney, of Los Angeles, Calif. The Slaytons have one son, Kent, 2.

Slayton attended primary and high schools in Sparta, graduating from Sparta High School in 1942. He entered the University of Minnesota in January 1947, and was graduated with a degree in aeronautical engineering in August 1949.

He entered the Air Force as an aviation cadet in 1942 and after instruction at Vernon, Tex., and Williams, Ariz., won his wings in April 1943. He flew 56 combat missions in B–25's in Europe with the 340th Bombardment Group (Medium). In mid-1944, he returned to this country as a B–25 instructor pilot at Columbia, S.C., and then served with a unit checking out pilots in the A–26. He joined the 319th Bombardment Group (Medium) and went to Okinawa in April 1945, where he flew seven combat missions over Japan. He was an instructor pilot in B–25 aircraft for about a year after the war. Following his graduation from the University of Minnesota, he was an aeronautical engineer with Boeing Aircraft Co., in Seattle, Wash., until recalled in early 1951 to active duty with the Air National Guard, in which he maintained membership during his student days at the University of Minnesota. On his recall, he was assigned to Minneapolis as maintenance flight test officer of an F–51 squadron. He then spent a year and one-half at 12th Air Force Headquarters as technical inspector, and a like period as fighter pilot and maintenance officer with the 36th Fighter Day Wing in Bitburg, Germany. He returned to the United States in June of 1955 and attended the Air Force Flight Test Pilot School at Edwards Air Force Base, Calif. Since January 1956 he has been an experimental test pilot at Edwards, where he has flown all jet fighter type aircraft built for the Air Force. His last assignment was chief of Fighter Section A. He has 3,400 flying hours, 2,000 in jets.

Slayton holds the Air Medal with Cluster.

His hobbies are hunting, fishing, shooting, archery, photography, and skiing.

Senator STENNIS. These young men seem to be from 32 to 37 years of age—I have understood that they would be on leave for a while and at the end of that time they will be in Washington and we are going to invite them to come up and meet with our commitee.

What about that, Mrs. Smith?

Senator SMITH. I think that would be very nice.

Senator STENNIS. We hope we can meet with the entire committee and put some animation, some additional animation in these charts.

Mr. Cortright, you are in charge. You may present your next witness, please.

Mr. CORTRIGHT. Senator Stennis, although the guidance equipment does not have as much personality as the pilots we have been talking about, it is the subject we are to continue with here.

Mr. Benjamin Milwitzky will talk on midcourse and terminal guidance.

Senator STENNIS. All right, Mr. Milwitsky. We heard from you yesterday. We are glad to have you back. You may proceed in your own way.

TESTIMONY OF BENJAMIN MILWITZKY, HEAD, GEODETIC AND NAVIGATIONAL SATELLITES PROGRAM, NASA—Resumed

Mr. MILWITZKY. Thank you, sir. The last speaker this morning talked to you about injection guidance which is used during the early powered phase of a space vehicle mission to inject the vehicle into a trajectory along which is can coast to its destination.

NEED FOR MIDCOURSE AND TERMINAL GUIDANCE

For many deep space missions, such as those where we might want an accurate approach to a planet, this type of guidance is not sufficiently accurate to do the job. The situation might be likened to trying to aim a rifle at a target many miles away. The amount of accuracy that you would require in your aiming just cannot be achieved. For missions of this type we therefore have to devise equipment that will operate subsequent to the injection phase and which will guide the vehicle all the way to the target.

The problem basically resolves itself into two natural phases, a midcourse navigational phase and a terminal guidance phase. In the midcourse phase we could use celestial navigation techniques very much like those the mariner uses, observing the stars, the planets, and the sun. Or, we could use radio techniques to track and control the vehicle from the earth.

In the terminal guidance phase, we would probably base our guidance on radar or optical sensing techniques which would actually look at our destination. The terminal guidance phase requires especially accurate guidance because many of our missions will have specific scientific purposes necessitating closely controlled maneuvers.

For example, we might want to place a very accurate orbit about a planet for a particular scientific investigation or we might want to effect a soft landing on the moon or on a planet. I think you can see that this terminal phase is the most rigorous in terms of the accuracy required.

I should like to point out that the midcourse phase is one in which the vehicle is coasting. It is coasting along a planetary ellipse following Kepler's laws. The vehicle itself does not have any inherent means of changing its course. It does not have any means of steering itself. If we want to change its course, we have to provide it with an impulse.

During the near future we will have to carry along additional chemical fuel to operate the rocket engine to supply this impulse. At a later date we may have ion engines, nuclear rockets, or we may even be able to use the pressure of the energy coming from the Sun—solar radiation pressure—to effect these changes in the course of the vehicle.

MIDCOURSE NAVIGATION SCHEMES

It may be of interest to you to see some of the ideas which might be considered for performing the midcourse navigation function, so we

have prepared a chart which shows concepts of a celestial and a radio technique. With the celestial technique the device is completely self-contained in the vehicle. With the radio technique the vehicle is essentially guided from the ground.

The celestial technique would employ optical or infrared sensors which would be used as Sun seekers, star seekers, or planetary seekers. For example, this one might be observing the Earth, or it might be observing the destination planet. These optical or infrared seekers would be small telescopes which focus light on a photoelectric cell which generates an electrical impulse. Very clever devices and systems have been developed whereby these seekers will first start out hunting and then will lock onto their target, planet or star as the case may be; and when this happens you have a situation where one seeker is pointing this way, another seeker is pointing that way, a third may be pointing another way.

As the vehicle moves through space its position relative to the celestial bodies changes so that these angles change, and inside the vehicle we have devices which measure these angles. These measurements are transmitted to a computer in the vehicle. This computer performs the navigational calculation to determine where the vehicle is. It has stored in it the formulas for calculating the best trajectory from the point where the vehicle is to where we want it to go. It further computes the amount of impulse required to make the vehicle perform this maneuver. It turns these numbers into actual physical commands which operate this rocket. First, it tilts the rocket motor, that is, swivels it in the proper direction. It then meters out the amount of fuel required to provide the necessary impulse. It finally fires the rocket motor to put the vehicle on the proper trajectory to take it to its destination.

Also shown on the chart is an inertia wheel coupled to a Sun seeker. Its purpose as shown here would be to effect control of the orientation of the vehicle about this axis. This would be an attitude stabilization system.

Also shown is a stable platform. You have heard about these in connection with injection guidance. This might be one that we have used during the injection phase. We could also use it during the terminal guidance phase. Normally in the midcourse phase it would be turned off to conserve energy. But there are certain times during the midcourse phase when we would need it. During the time that we are performing a maneuver, that is, firing the rocket, for instance.

The stable platform is an extremely sensitive thing. Its instrumentation gives us a means for sensing the relatively small changes in velocity and direction that we want to impart to the vehicle. So we need it as a sensor during the time that we are firing the rocket motor. Also, if we did not have it working at that time, the rocket motor might perhaps cause the vehicle to tumble. The stable platform might also be used under other situations. Assume that we have an orbit around a planet. At some point in this orbit the Sun may be hidden by the planet. The stable platform gives us a memory whereby we can remember where the Sun is and when we come out from behind the shadow of that planet, it makes it much easier to pick up the Sun again on the Sun seeker.

The celestial system has one very strong advantage and that is this: The seekers operate purely in terms of the angles of one planet with respect to another. They do not depend at all on absolute distances; and yesterday, I think you will remember, you heard that we know these angles much, much better than we know the distances involved. So a system like this is inherently very accurate.

The other type of system which could be used for midcourse navigation is the radio system and I will try to very briefly explain this.

We have on the ground a radio transmitter, a very powerful transmitter which is always tracking the vehicle. It sends out radio impulses to the vehicle which are received on the vehicle, and retransmitted back to the ground. By comparing the outgoing signal with the incoming signal, we can determine the distance of the vehicle from the station, and we can determine the velocity of the vehicle.

This information is transmitted to a guidance computer and this computer does somewhat the same job as the other one did. It determines what commands we have to transmit to the vehicle to cause it to change its course in a manner necessary to get it to its destination. These commands are computed here. They are transmitted to the antenna, back to the vehicle in a coded form, received by the vehicle, decoded in terms of actual push-pull type mechanical operations which swings the rocket motor and fires the necessary charge for course correction.

I want to say that these are not real systems. I have tried to show here essentially the elements of the problem, the types of equipments which would go into the systems, and the philosophies which could be used to do the job.

TERMINAL GUIDANCE SCHEME

You might be interested in a similar analysis of the terminal guidance situation. This system might be considered as one that would be suitable for landing on the Moon. Quite a long distance away from the Moon we would make use of these horizon scanners. You heard about horizon scanners in connection with the Mercury project earlier. These again are optical or infrared devices. There would be perhaps three of them looking out more or less like this, and they would hunt and they would find the line of demarcation between the surface of the Moon and the space beyond. There is a big temperature difference, and they work on this temperature difference to lock onto the horizon. As we come closer to the Moon, of course, this angle becomes larger and larger because the apparent diameter of the Moon becomes larger.

So this gives us a means of measuring our distance from the moon. It also gives us another very important thing, the direction of the vertical, because right through the middle of this angle is the line which connects the vehicle with the center of the moon. We have to know our vertical reference in order to make our landing. And so here we are approaching the moon at 7,000 to 9,000 feet per second. We have to kill off the velocity. We not only have to kill it off exactly in the vertical direction but any slight misalinement will give us a horizontal velocity; we would move sideways, hit a mountain, perhaps.

Here we need extreme accuracy. We would use a radar altimeter, such as we have in aircraft, for altitude. We would also use perhaps Doppler radio techniques, which would tell us very closely the vertical velocity as well as the horizontal velocity. Again this information would go into the computer. The computer would calculate the necessary commands to destroy these velocities; these commands would be transmitted to valves which control the flow of propellant into the engine and to gimbal the engine so as to properly slow down the vehicle. The system would also use inertial elements and autopilots because we are applying power and we need some means of stabilizing the vehicle during this operation. If we do it properly we can set the thing down in a very gentle manner.

ATTITUDE CONTROL

The previous discussion has been almost completely concerned with the control of the trajectory of the vehicle. In addition we have to control the attitude of the machine. For many purposes we have to stabilize the attitude, and to stabilize the attitude means that we have to be able to control the rotation of the vehicle about any one of its three axes.

And there are several ways of doing this.

In space, where we don't have any real power, where we are coasting, we might use small gas jets. These gas jets would be operated either together or differentially. Let me try to explain. Assume that one gas jet were made to push one way, and the other gas jet were made to push the other way. This would give us a rolling moment. If this gas jet and this gas jet were pushing in the same direction it would give us a yawing moment; by this technique we could make the vehicle rotate about any of its three axes.

Or we could use momentum wheels. These make use of the principle that with every action there is an equal and opposite reaction. Here we have a motor and a wheel. If we speed up the wheel in this direction, I think it is clear that there is going to be reaction which is going to make the vehicle turn the other way. We can also do this about all three axes.

During the terminal phase where we do have the power available, we would use the same techniques that are being used at the present time during the launching or injection phase. We might use vernier rockets, which are very small rockets that swivel around and give us the necessary control; fixed rockets which could be operated either differentially or together, gimbaled motors that swing around, or jet vanes which deflect the exhaust of the vehicle, and we would obtain our control forces this way.

STATUS OF MIDCOURSE AND TERMINAL GUIDANCE

Now, I know you are interested in the status of midcourse and terminal guidance. This status is something like this: At the present time we do not have an operational system. On the other hand, systems which could be used employ components many of which we can adapt from existing components and many others of which are under very serious investigation and study.

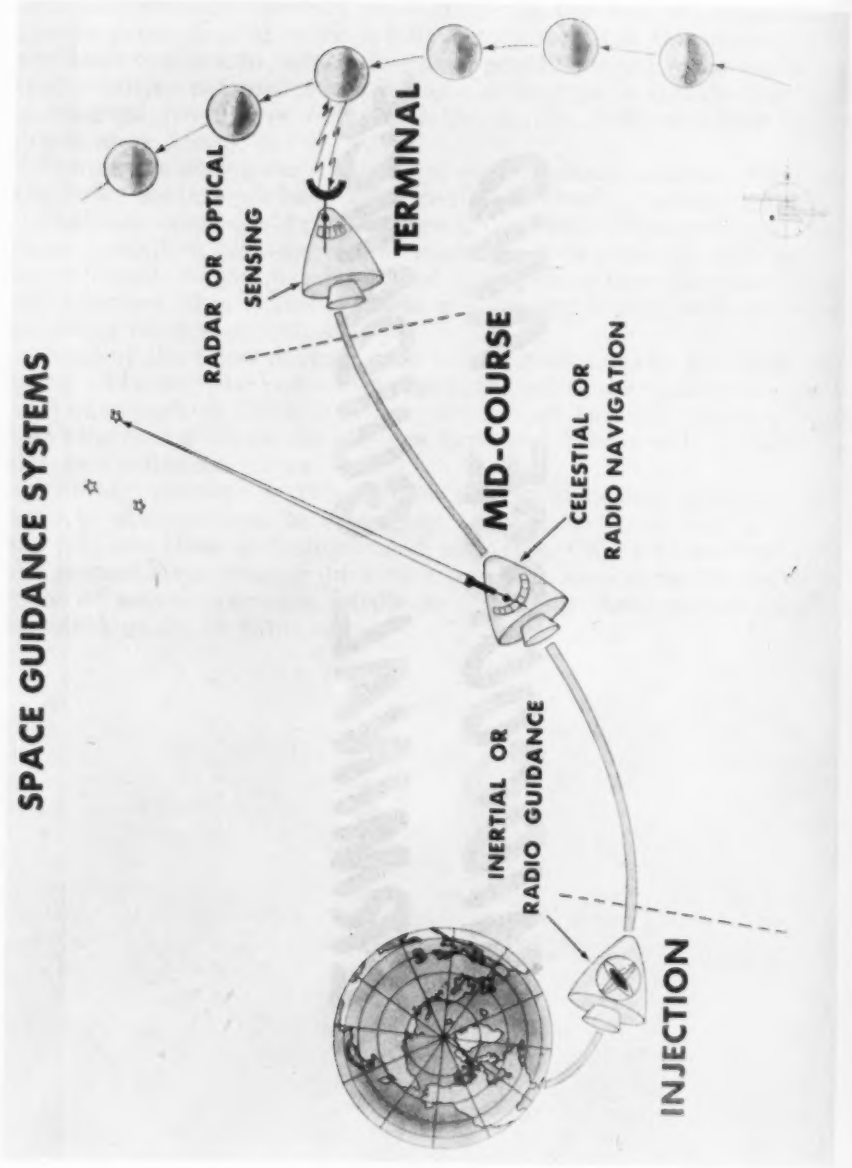
For example, you saw that we would rely heavily upon these optical or infrared seekers or sensors. There is a tremendous amount of research being done now in this area and some of the results that I have seen recently are very promising. In the field of communications a great deal of work is being done to study the propagation problems in space, to develop low noise amplifiers and radio receivers, very sensitive equipment to pick up the very weak signals that will be received from these vehicles; later on, Mr. Jaffe will talk about this in more detail.

Computers play a very important part in these systems. Here we are lucky because we have inherited an advancing technology from the ballistic missile field; at the present time what is happening is that these computers are being made much larger in terms of their capacity to handle bigger problems, and at the same time they are being miniaturized, that is, being made smaller physically, and also they are being made more reliable.

Some of the other devices, such as radar altimeters, airplanes use those. The Doppler radio techniques, the police use those so they are well advanced. I think it is fair to say that basically many of the ingredients for these systems are here and others will be here in the not too distant future.

The big problem is this: These are sophisticated systems. We have to analyze them to determine which is the best way of doing the job, and these are complicated problems. Work is underway at the present time to come up with a program leading to the development of actual operating hardware for doing these midcourse and terminal guidance functions.

MIDCOURSE AND TERMINAL GUIDANCE


SPACE GUIDANCE SYSTEMS
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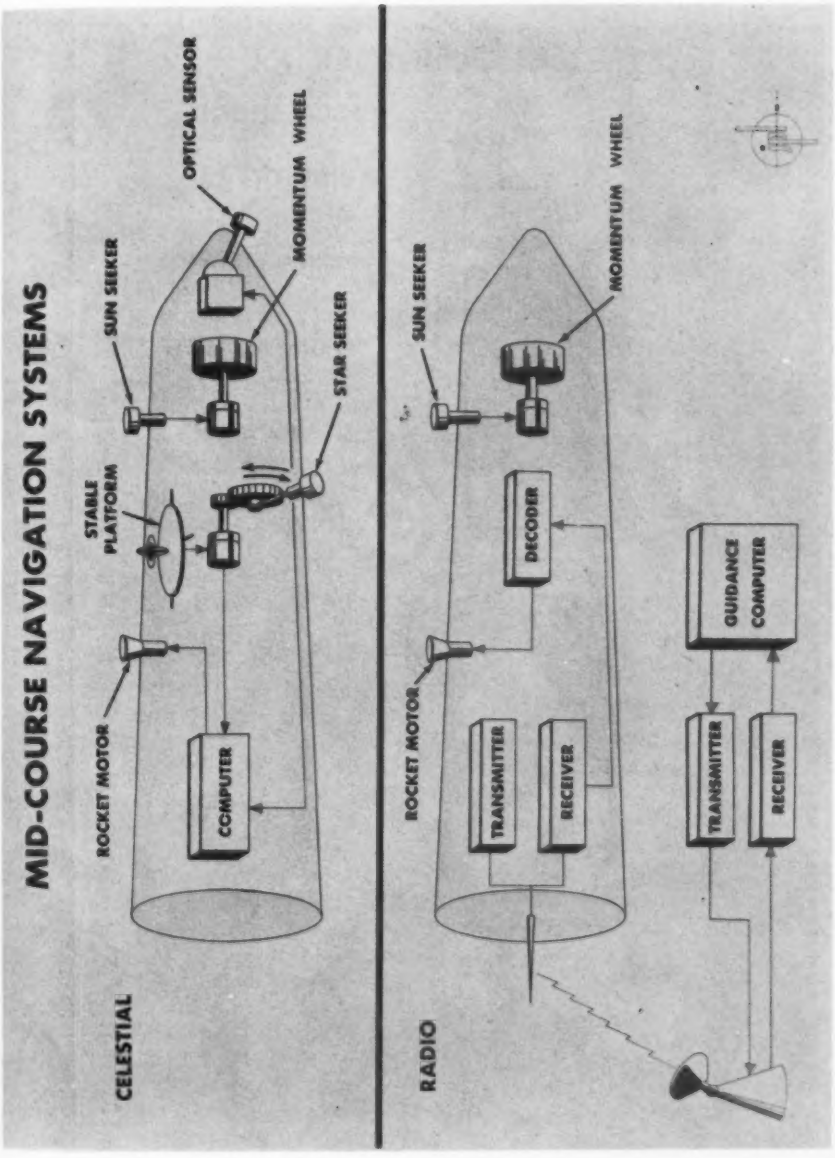
TERMINAL
MID-COURSE
CELESTIAL OR RADIO NAVIGATION
INERTIAL OR RADIO GUIDANCE
INJECTION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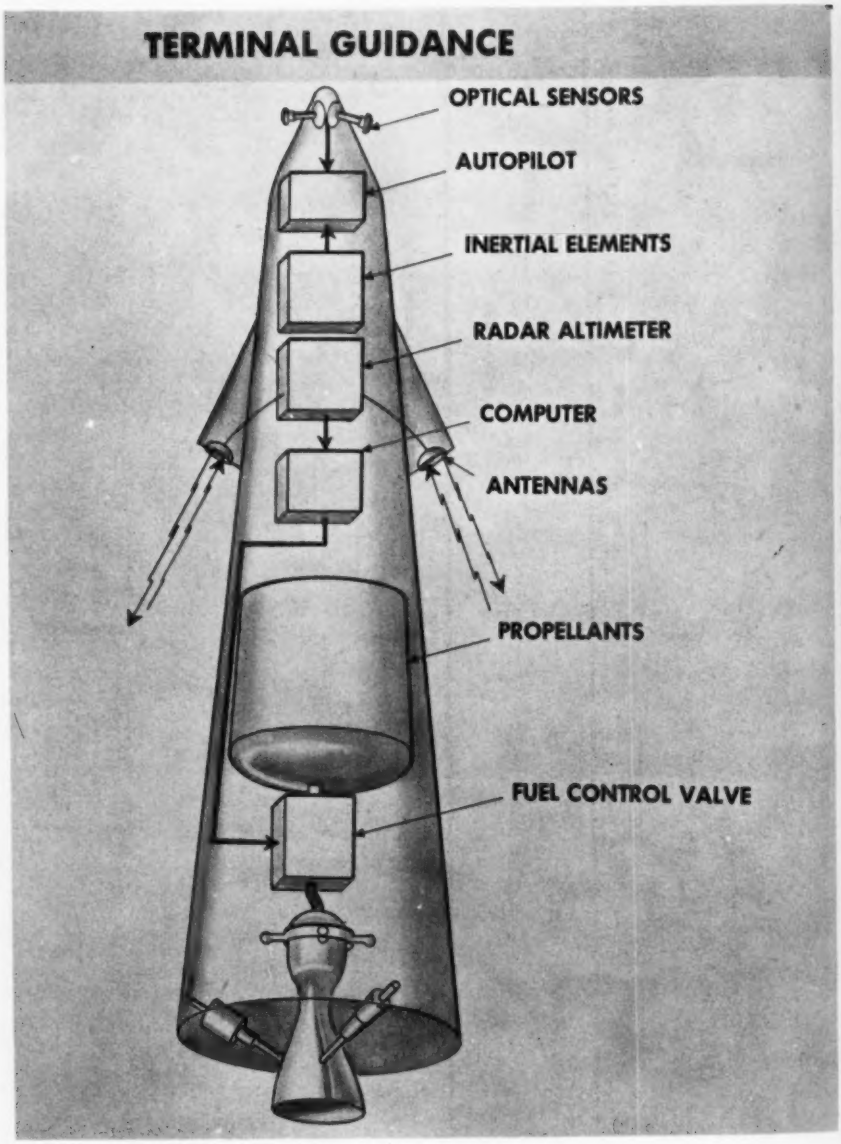
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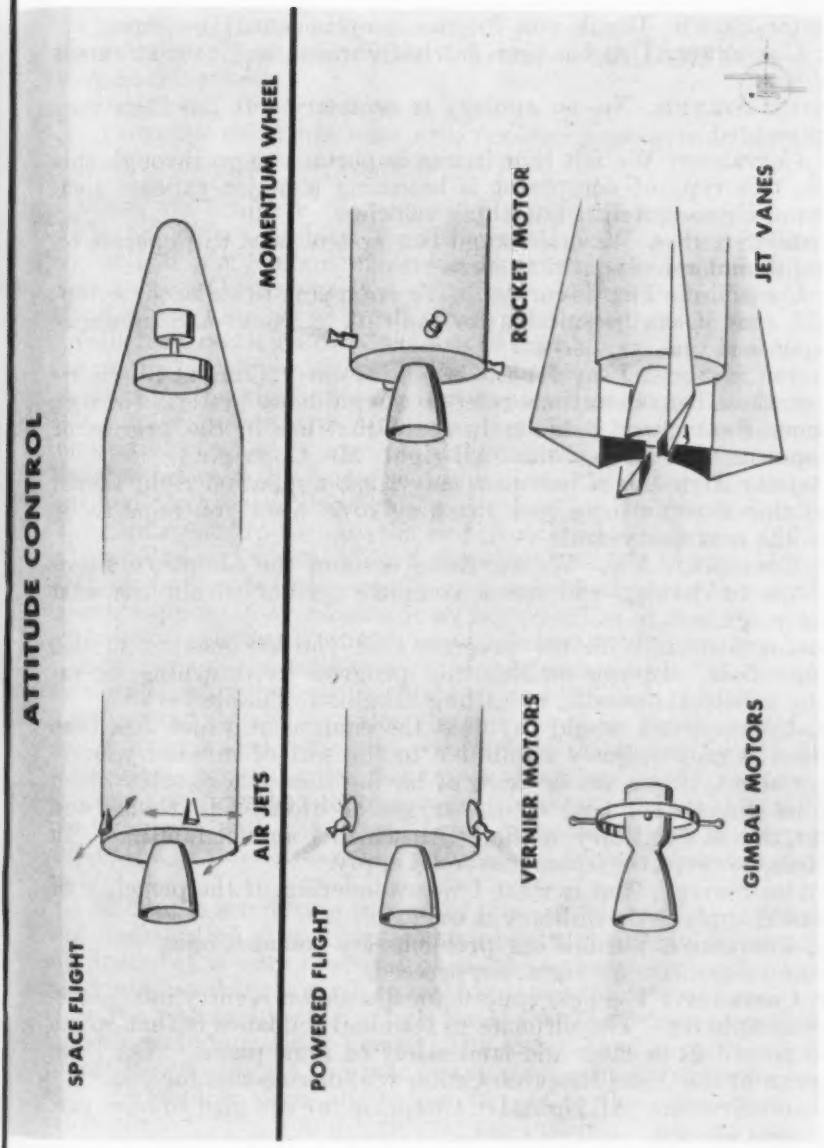
ATTITUDE CONTROL
SPACE FLIGHT
AIR JETS
MOMENTUM WHEEL
POWERED FLIGHT
VERNIER MOTORS
GIMBAL MOTORS
ROCKET MOTOR
JET VANES

Mr. CORTRIGHT. If you have guidance questions this would be the time.

Senator STENNIS. Mrs. Smith, do you have any questions on the subject?

Senator SMITH. Thank you for the compliment. [Laughter.]

Mr. CORTRIGHT. This has been fairly technical, and to that extent I apologize.

Senator STENNIS. No, no apology is necessary. It has been very well presented.

Mr. CORTRIGHT. We felt that it was important to go through this because this type of equipment is becoming a major expense item in our missile and satellite launching vehicles.

Senator STENNIS. We understand this system here will operate on many different vehicles, is that correct?

Mr. CORTRIGHT. That is correct. We are trying to make the equipment so that it can be suitable for multiple missions and minimize the expense in that way.

Senator STENNIS. I say for the benefit of our visitors at this hearing that these demonstrations refer to the guidance systems for men in space—the manned vehicles in space that are in the process of development on a large scale. All right, Mr. Cortright?

Senator SMITH. Mr. Chairman, may I ask a question right there? All of this that we have been listening to is what you hope to do within the next few years?

Mr. CORTRIGHT. Yes. We are using some of the components now and hope to develop and use a complete system within the next several years.

Senator SMITH. With the progress that you are making in this guidance field, are you making any progress in returning or exploding a ballistic missile, or calling a ballistic missile back?

Mr. CORTRIGHT. I would say that the equipment which has been discussed is only vaguely applicable to the sort of mission you are talking about, if you are thinking of having a missile in orbit which could be directed to land on the target or directed to return and reenter, this is a military mission with which I am not familiar. In principle, however, the techniques could apply.

Senator SMITH. That is what I was wondering, if the principle of this would apply to the military as well.

Mr. CORTRIGHT. I think our problems are common ones.

Senator STENNIS. All right, sir, proceed.

Mr. CORTRIGHT. The next subject for discussion is entry into planetary atmospheres. The ultimate in terminal guidance is that which would permit us to enter and land safely on some planet. Dr. Dean Chapman of the Ames Research Center will discuss this for you.

Senator STENNIS. All right, Dr. Chapman, we are glad to have you. Come right around.

TESTIMONY OF DR. DEAN R. CHAPMAN, RESEARCH SCIENTIST, HIGH-SPEED RESEARCH DIVISION, NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.

Dr. CHAPMAN. The subject on which I am going to speak is the entry of manned space vehicles into some of the various planets. It

is really just one of at least five or six of what you can call major problem areas that are associated with manned space flight, inasmuch as any of these manned missions—even if it is just to the moon and back, let alone to any of the planets and back—are in the future.

Everything that I have to say will of necessity be concerned with current research, that is it is far too early to talk about items of hardware on this subject.

PROBLEMS OF ATMOSPHERE REENTRY IN TERMS OF HEATING AND DECELERATION

When we compare the reentry problem for a manned spaceship with the reentry problem for either the ICBM or the satellite with which I think you are more familiar, there are several important differences. One is purely a quantitative difference. The spaceship about which I am going to talk enters the atmosphere faster. That is, it falls from much greater distances to the planet than either the satellite or the ballistic missile does, so it comes in faster. In fact it has about twice the kinetic energy that the satellite has. But apart from this purely quantitative difference there is a much more important qualitative one and it concerns the guidance. There is an interrelationship between the guidance problem and the reentry heating problem and the reentry deceleration problem for the manned spaceship which relationship we have not had to contend with before and which is new to us, and I would like to take just a second to explain that.

If we have a ballistic missile and instead of going to exactly the target, suppose it overshoots it by say 50 miles or undershoots it by 50 miles. This doesn't make any difference to the reentry heating. It is just about the same and it does not make much difference to the decelerations so the reentry problem and guidance problem in that sense are not connected. But now for the space vehicle if this overshoots its intended trajectory coming into the planet by 50 miles or undershoots it by 50 miles, this can be catastrophic as far as the accelerations are concerned to an occupant in this ship and, also, the heating problems with this slight error in guidance can be very much different and these differences I think will become clear in a moment here.

I think it is interesting that all of these problems of reentry heating and deceleration that I am going to talk about can be completely eliminated if it were practical to use the technique of rocket braking illustrated on this chart which technique was thought of and described at least a hundred years ago by a lot of far-thinking, science-thinking writers, including Jules Verne. The idea is that in approaching the planet here the rocket thrust is just turned on in a reverse direction so that the vehicle slows up before it gets to the outer edge of the atmosphere. This would eliminate the problem. But the only catch is that it takes so much fuel to be burned in slowing up the vehicle for a planet like the Earth that it would be very costly in weight.

We would have to build the entire vehicle about 50 times as large, so we would rather take the reentry problem, solve the reentry problem, than we would build a vehicle maybe 30 to 50 times as large. One method of using the air to slow the vehicle down instead of the fuel which has been considered for about 30 years and which looked very attractive until last year is the multiple-pass atmosphere brak-

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ing. This idea, which I will go over very quickly, is that the spaceship comes in at a trajectory about like this and it passes once just in a grazing sense to the edge of the atmosphere, slows down a little and tightens the orbit and then repeats the procedure.

In this way the slowing down is done in steps and is nice from the reentry heating and deceleration viewpoint but the problem, of course, one of them, is that the vehicle must pass several times through the radiation belt which is undesirable certainly because if for no other reason it would impose an impossible weight penalty for us.

So the type of entry that is being considered most seriously is a single pass type wherein, say, the space vehicle enters again along some such trajectory and on the first pass it enters the atmosphere and lands.

Now, for a comparison here we have illustrated also the nearly circular trajectory of the manned satellite capsule. You will notice, as was mentioned in one of the earlier presentations also, the manned satellite capsule avoids the radiation belt by also orbiting between the Earth and the inner radiation belt.

Now, the spaceship has to avoid, or can avoid, the radiation belt by the proper guidance and the proper path. Actually this problem of avoiding the radiation belt is very easy compared to the guidance problem of hitting a certain entry corridor which the space vehicle must hit and which is illustrated on this chart.

We have the planet here and we are illustrating different possible approaches to trajectories. If we happen to overshoot too much and approach along a trajectory that is, say, one of these two outer dotted trajectories, the vehicle will pass too far away from the planet, too high in altitude, so that there is no air out there and no atmosphere to slow you down, so it just goes around and keeps on going and doesn't land.

Now, on the other hand, if the vehicle comes in too close, undershoots too much, it will intercept the atmosphere at such a steep angle that the impact will result in decelerations that are too large for a human occupant. So, by the time you rule out all of these areas, all we are left with is a narrow entry corridor down through which the vehicle must be guided in order to have enough drag on the one hand to land and in order not to have too much to result in too large decelerations.

NARROW REENTRY CORRIDOR IMPOSES SEVERE GUIDANCE REQUIREMENT

One of the points I want to make here concerns the narrowness of this entry corridor. The width of the corridor here at the neck for the earth's atmosphere for any nonlifting or bulletlike or nose-conelike object is only 7 miles wide.

If we make a much more complicated vehicle, a lifting vehicle which can maneuver both through angle of attack as well as laterally, the corridor can be extended to about 60 miles, which is a much easier guidance problem but still difficult.

The penalty that we would have to pay, of course, is the complexity of a lifting vehicle compared to a nonlifting one. And we can think of the lifting vehicle, for example, as a supersonic airplane and the nonlifting as a bullet or we can think of this as a lifting manned spaceship and this is a nose cone.

It has taken a lot more research and development to develop the supersonic airplane that it has the bullet, and by the same token it is going to take an awful lot more research, development, effort, time, and so forth to develop a lifting manned spaceship than it has taken to develop a nonlifting ballistic vehicle.

I would like to give you an illustration here of roughly the degree to which this presents a problem. Even with the lifting vehicle where the corridor width is 60 miles, this is small compared to the diameter of the planet, 8,000 miles for the earth, this 60 miles is a little less than 1 percent of the earth's diameter.

The skin on an apple is a little less than 1 percent of the apple's diameter. So this guidance problem of hitting this entry corridor is just about the same guidance problem that William Tell would have had, that is, if he had had to shoot the skin off the apple instead of just hitting the apple. Now that sounds like a rather severe guidance requirement, and it is. It is just a very difficult one, but certainly not impossible by any means.

On this next chart, to illustrate just for purposes of orientation what the entry corridors look like for Venus and also for Mars, they are quite different for the different planets.

These are roughly to scale. For the Earth and Venus it is this narrow white corridor as illustrated, but for Mars the entry corridor, the white part, is much broader. Now when we consider other objects in the solar system we encounter even more diversified extremes. Jupiter, for example; the entry corridor on that to this scale would be so narrow that I could hardly illustrate it with a pencil line. But for still other objects like Titan, the satellite of the planet Saturn, the entry corridor for it on that is so broad that it covers the entire breadth of the satellite and is even broader for Mars.

COMPARISON OF AERODYNAMIC HEATING PROBLEMS OF SPACESHIP AND BALLISTIC VEHICLE

On the next chart here illustrated is a little about the aerodynamic heating problem that would be encountered for a spaceship of this type by comparing this with the aerodynamic heating problem for the ICBM, and also the manned satellite; what is charted here is the rate of heating, the rate at which heat energy is poured into these vehicles as a function of the time that has elapsed after the entry started. But you can see that the ballistic vehicle, the ICBM, encounters a very intense heating rate but only for a few seconds, 10 seconds or so.

In contrast at the opposite end here is the spaceship which encounters much lower heating rates, but must endure them for much longer times. Actually this can result in a more severe heating problem. An example here, we can think of by imagining that say in a far place over here we have a flame that is very intense and on the other side of the room we have a pan of boiling water. If we put a glove on our hand and go over to the flame even though it is much hotter than the boiling water and pass our hand through it for a few seconds and we only have to endure it for a few seconds and take it off, the glove will protect us and our hand won't be burned.

But if we place this same hand in the same glove in the boiling water even though it is not nearly at hot as the flame and have to endure it and leave our hand there for 20 minutes we can clearly get burned.

As a matter of fact, in some respects this aerodynamic heating problem is more severe for the spaceship than it is for the ballistic vehicle, and this shows up in terms of the weight which the current technology would have in a heat shield protection.

In a bar graph form here we have illustrated the relative weights that would have to go into the heat shield compared to the total vehicle weight.

The total vehicle weight is the overall weight. You can see the fraction is not very great for either the ballistic missile, about 25 percent, something like that, or the manned satellite or the manned spaceship, providing the spaceship happened to come in near the undershoot or the lower limit of that entry corridor.

But if through a slight guidance error it happened to come in near the overshoot boundary, the amount of heat that would have to be absorbed would be much greater and the total weight in the heat shield would amount to on the order of three-fourths of the weight of the vehicle and this, of course, doesn't leave much left over for the payload or structure.

The point I would like to register here is that all of the work that has been done on the aerodynamic heating problem for ballistic missiles provides for us a really good start on the aerodynamic heating problems for a spaceship but does not solve the problem for us by any means.

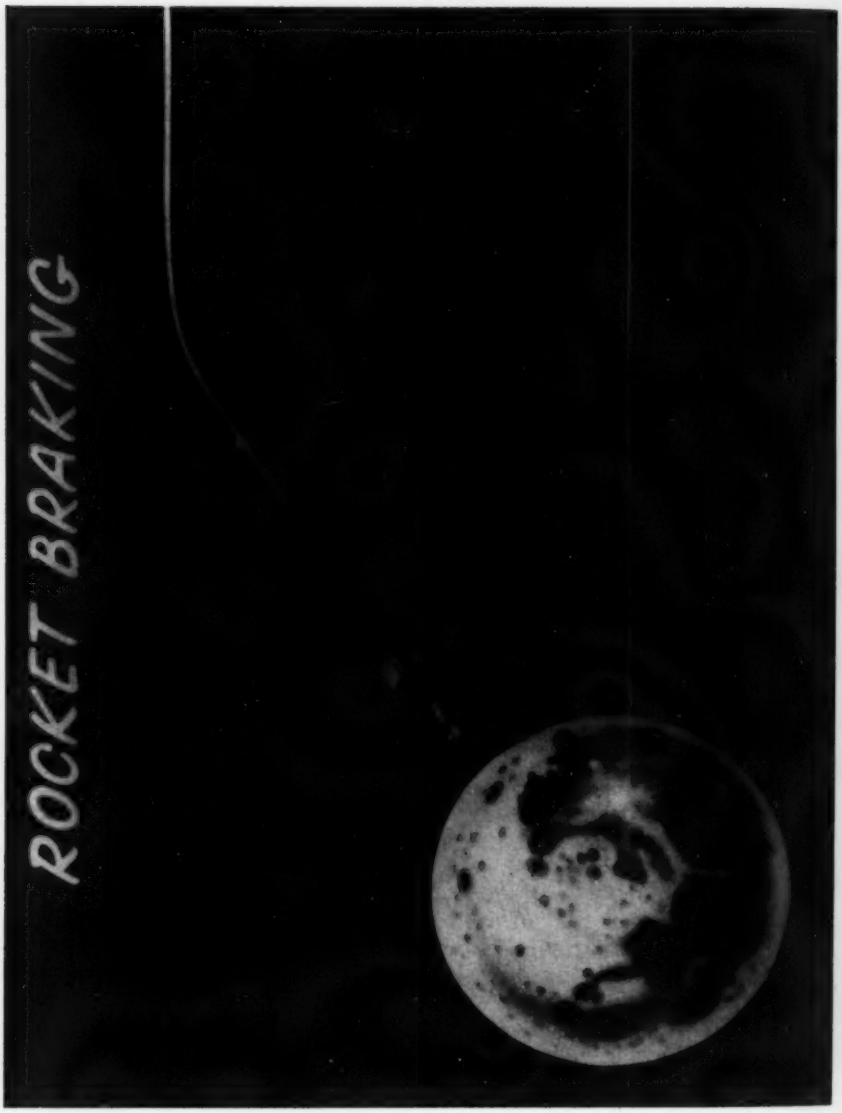
We need to develop a lot more efficient and a lot more flexible methods of heat protection than have been developed thus far.

Now the last point I have illustrated here on this final chart concerns the relative degree of severity of the deceleration problem and the heating problem for the different planets. On the left here we have charted the deceleration in G's as a function of the lift-drag ratio, that is different shapes here. Zero would be a nose cone, one would be roughly a spaceship, a lifting spaceship at about this angle. The point here is that the curve for Venus is a little lower than for the Earth, a little less deceleration. The decelerations encountered in reentering Mars would be much less than either Venus or Earth, and likewise we have a similar situation here for the temperatures.

This is for a radiation-type scheme. The temperatures encountered in Venus would be somewhat less than the Earth and the temperatures for Mars during this entry process a lot less.

So the point is that, at least as far as we know now, once we learn how to handle the aerodynamic problems and deceleration problems for reentering into our own atmosphere, we will be well along toward the solution of those problems for at least our neighboring planets, Mars and Venus.

ENTRY INTO PLANETARY ATMOSPHERES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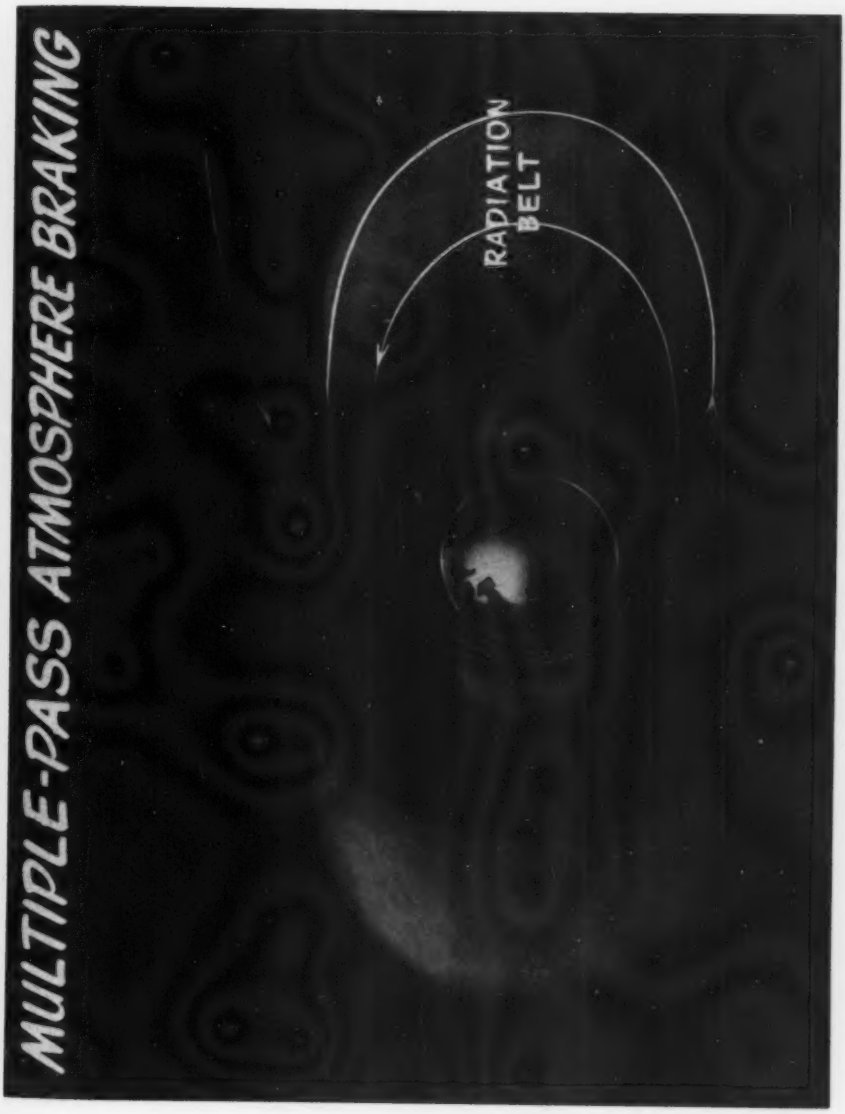
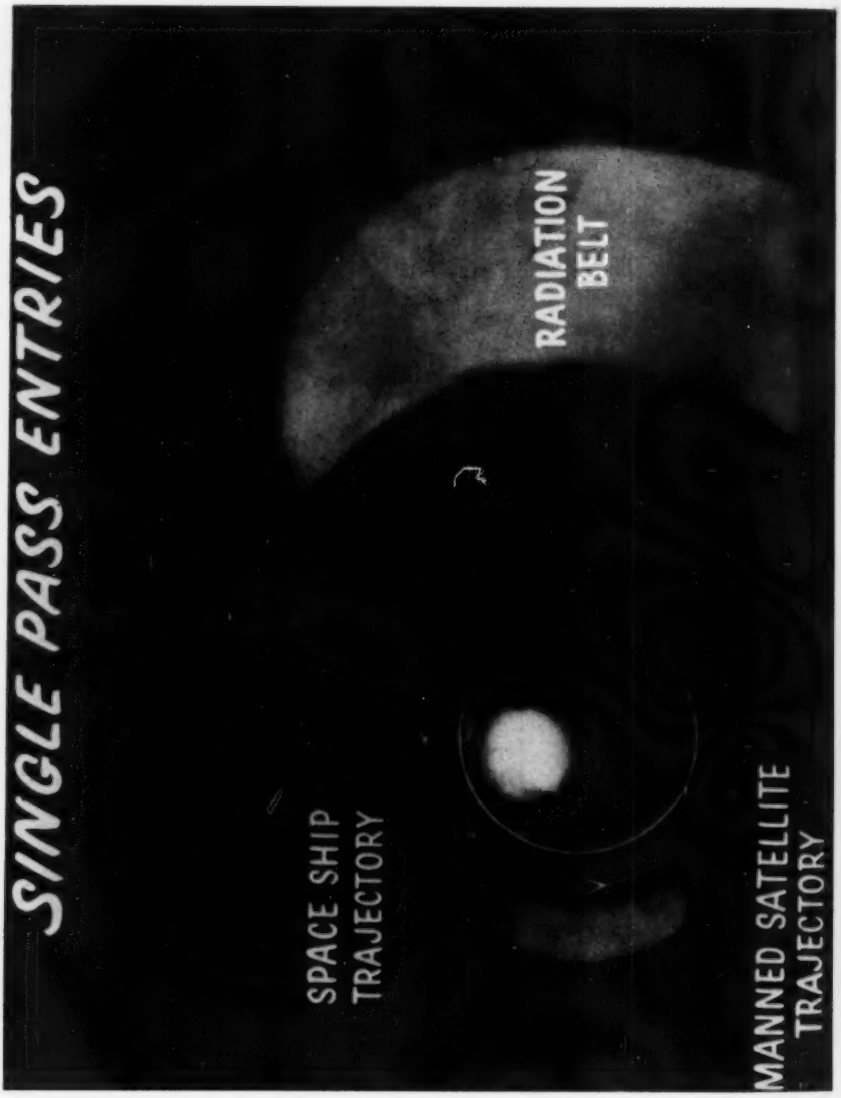
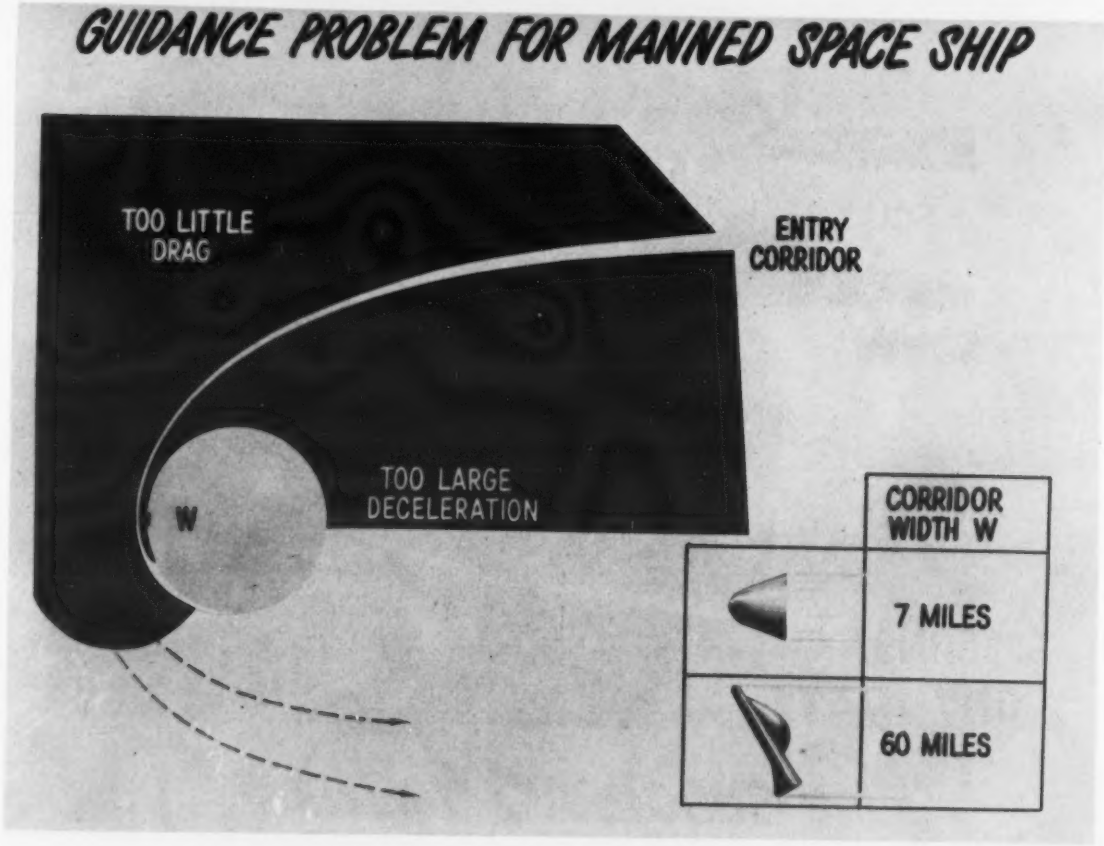
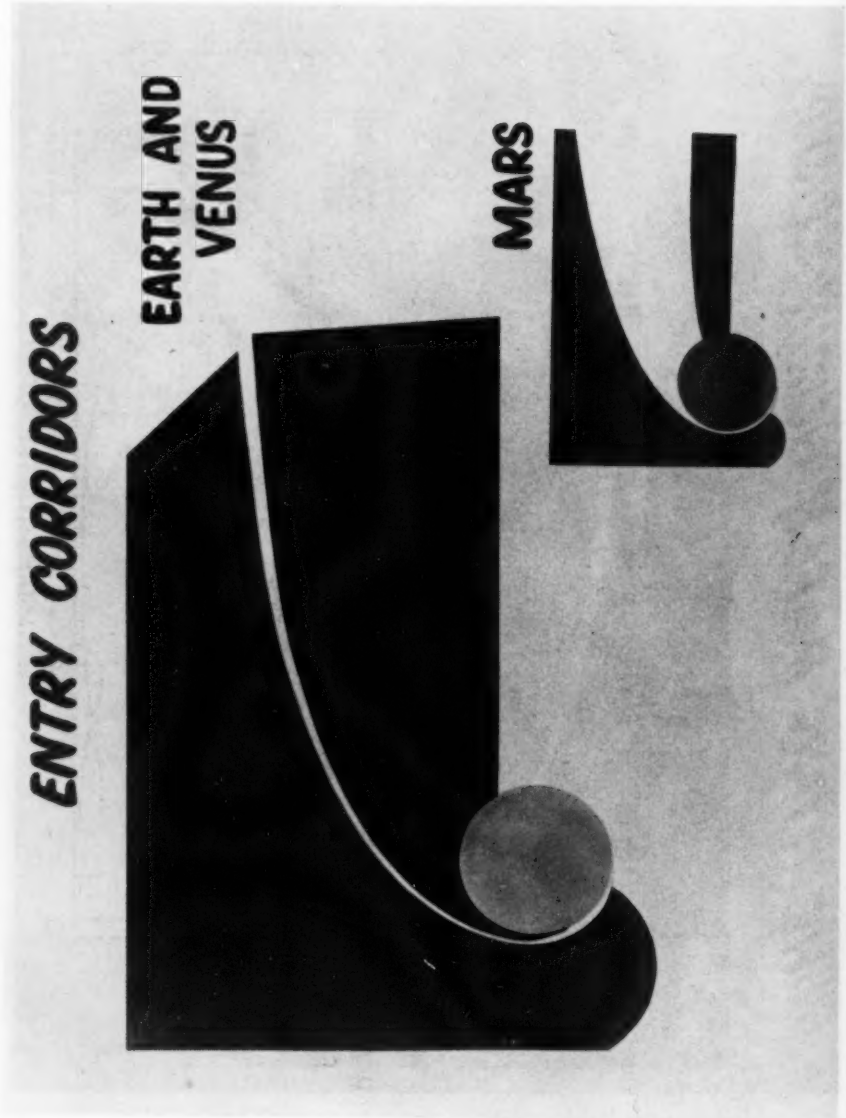
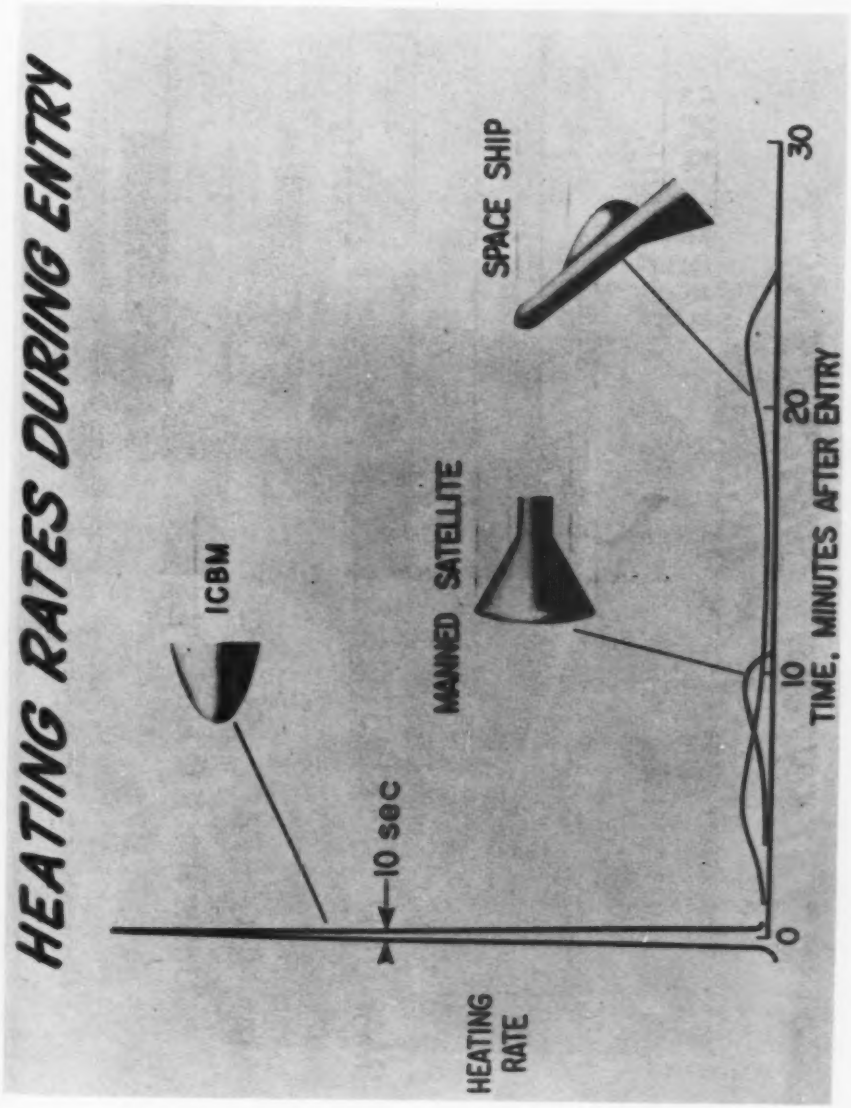

MULTIPLE-PASS ATMOSPHERE BRAKING
RADIATION BELT

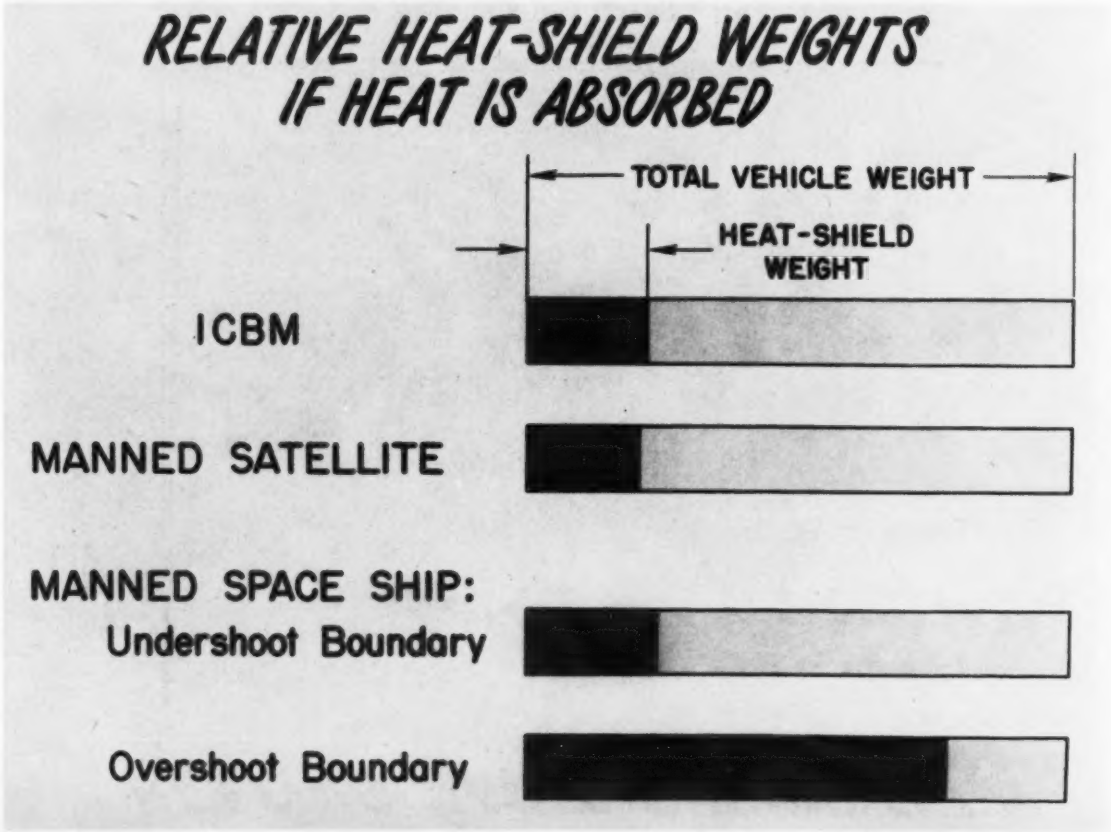

SINGLE PASS ENTRIES
SPACE SHIP TRAJECTORY
RADIATION BELT
MANNED SATELLITE TRAJECTORY

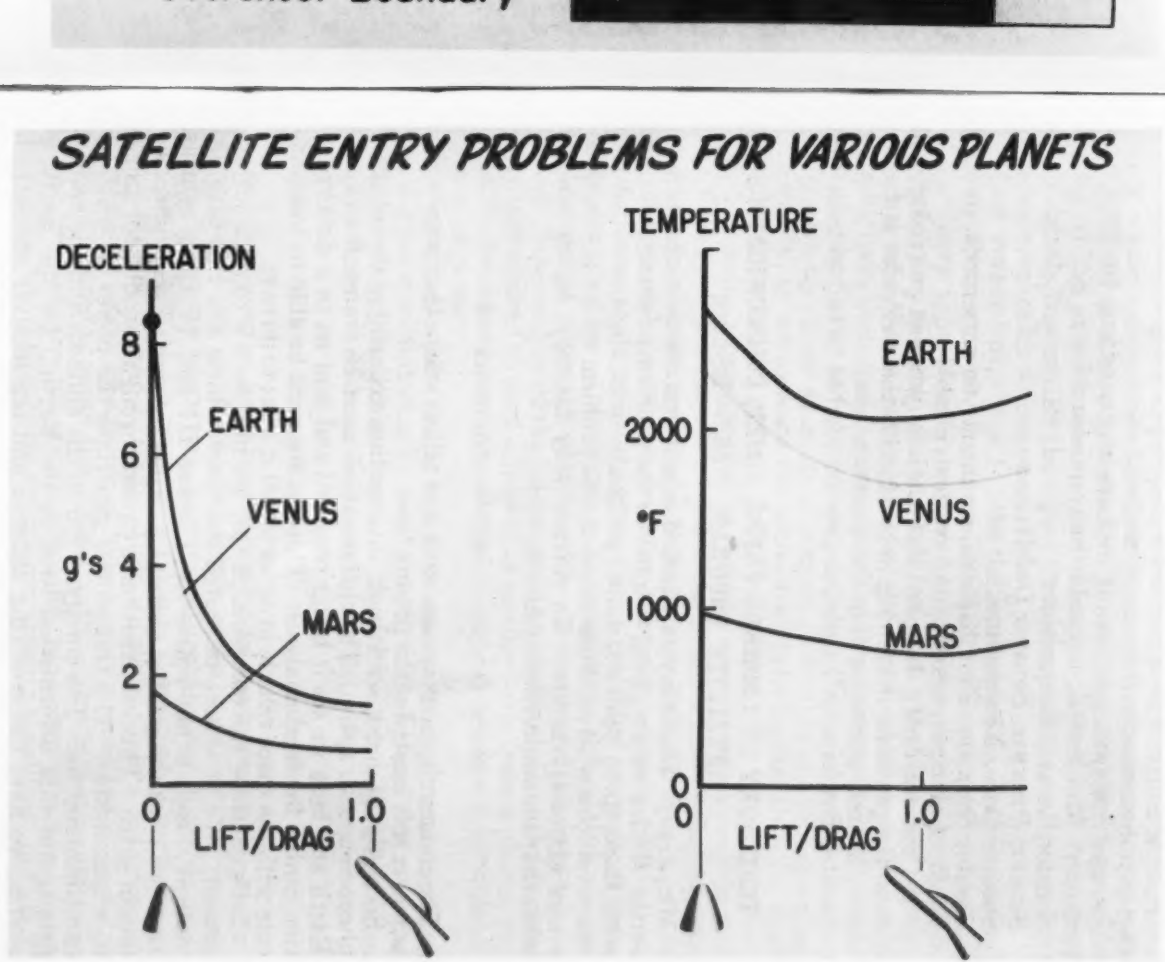
TRAJECTORY


GUIDANCE PROBLEM FOR MANNED SPACE SHIP
TOO LITTLE DRAG
ENTRY CORRIDOR
TOO LARGE DECELERATION
W
CORRIDOR WIDTH W
7 MILES
60 MILES


ENTRY CORRIDORS
EARTH AND VENUS
MARS


HEATING RATES DURING ENTRY
ICBM
10 sec
MANNED SATELLITE
SPACE SHIP
HEATING RATE
0
10
20
30
TIME, MINUTES AFTER ENTRY


RELATIVE HEAT-SHIELD WEIGHTS
IF HEAT IS ABSORBED
TOTAL VEHICLE WEIGHT
HEAT-SHIELD WEIGHT
ICBM
MANNED SATELLITE
MANNED SPACE SHIP:
Undershoot Boundary
Overshoot Boundary


SATELLITE ENTRY PROBLEMS FOR VARIOUS PLANETS
DECELERATION
8
6
4
2
g's
EARTH
VENUS
MARS
0
1.0
LIFT/DRAG
TEMPERATURE
2000
1000
0
°F
EARTH
VENUS
MARS
0
1.0
LIFT/DRAG

Senator STENNIS. All right, sir, we thank you very much.

Mr. Cortright, you indicate when there is a break now for questions. Who is your next witness.

Mr. CORTRIGHT. This again is another opportunity to have a break. Our next discussion will be on communications.

Senator STENNIS. Let's see if we have any questions for Dr. Chapman now. Mrs. Smith, do you have any questions?

Senator SMITH. No questions.

Senator STENNIS. Senator Dodd?

Senator DODD. No questions.

Senator STENNIS. Dr. Chapman, we thank you very much, sir. All right, Mr. Cortright, who do you have next, please?

Mr. CORTRIGHT. Mr. Leonard Jaffe, whom you met yesterday, will discuss the problem of keeping in touch with these vehicles at the extreme distances encountered in the space missions.

Senator STENNIS. All right, sir, we are glad to have you back with us.

TESTIMONY OF LEONARD JAFFE, CHIEF, COMMUNICATIONS SATELLITE PROGRAM, NASA—Resumed

Mr. JAFFE. Yesterday we talked about communications here on earth. Today we are going to consider the problem of communications with these space vehicles, more specifically with these so-called deep space vehicles where the communications problem with the vehicle becomes extremely severe. To refresh your memory, let us consider what the communications system must do.

SPACE COMMUNICATIONS REQUIREMENTS

The communications system must first tell us where the space vehicle is, where it is located at the present time.

Secondly, it must send back information regarding the observed phenomenon in space. This information must be transmitted to the Earth and here we see it being recorded and sent on to a data reduction center for final analysis. Thirdly, we must be able to communicate with the space vehicle in order to tell it what to do next.

Let's consider the components that go into such a communications system. We have here indicated the space vehicle and this diagrammatical sketch is not unlike the Pioneer III and IV space vehicles. Here we have the sensing element which is measuring some phenomenon in space. This information is passed through a modulator and on to a transmitter. The transmitter generates the power by which we can communicate. The energy is fed to the antenna and the antenna propagates this information back to the Earth. On the Earth, of course, we have the receiving antenna and the receiver necessary to pick up this energy and the subsequent recording and data analyzing equipment.

Now, what determines the range over which we can communicate? Well, first of all the transmitter, the amount of power than we can generate on the space vehicle. The more power we can generate the further the distance over which we can communicate. Secondly, the ability of the antenna to beam this energy back to the Earth. On the

space vehicles, or particularly the satellites that have been launched up until now, the antennas have been what we call omnidirectional antennas, that is, they radiate power in all directions and are thus very inefficient antennas for space vehicles. An efficient antenna is one which would concentrate this energy in the appropriate direction. The third element is, of course, the ground receiving equipment, the ability of the ground receiver and the antenna to detect very, very small signals, the smaller the signal that we can detect, the greater the distance over which we can operate.

If we were to imagine or to take the example of an omnidirectional antenna, that is one which radiates in all directions on the vehicle, and the ordinary type of receiver that is currently available today commercially, and calculate the amounts of power that it takes to communicate over distances in space, we get curves which look like this. Here we have indicated the satellite distances, here we have the lunar distance and finally the planetary distances. You will notice that the power goes up rather dramatically as we go further out into space.

Secondly, as we increase the amount of information that we want to transmit per second of time, the power goes up.

To transmit a television picture through space requires roughly 5 to 10 million times the amount of power required for narrow-band telemetry signals. To transmit voice through space requires perhaps 3 to 10,000 times the power required for telemetry signals. So, as we increase the amount of information we want to send per unit of time, the power goes up. One of the most interesting things that we can do if we are to approach planets with our space vehicles is to take a picture of the surface of the planet, and if we take a look at the amount of power required to send a television picture back from a planet, say Mars, we would end up with a figure of 10 billion watts, a formidable amount of power.

We have indicated this on the next chart. I might mention here that I have qualified this by saying 1953 techniques. Some of the techniques that I shall talk about are in current use today, so this dates back a little way. We can do a little better than this today.

TECHNIQUES FOR REDUCING POWER REQUIRED

Now what are the techniques whereby we can reduce this amount of power? First of all, we can increase the sensitivity of our receivers, our ground receivers, and provide what are called low noise amplifiers. Now if we were to develop a theoretically perfect low noise amplifier for the ground station, we could effect a reduction in the necessary power by a factor of 100, or this figure of 10 billion watts would be reduced to about 100 million watts. This is the theoretically perfect receiver, and we are approaching this today with the advent of so-called mazer amplifiers and the parametric amplifiers, but much work remains to be done. But this is as far as we can go with ground receivers.

What can we do next? Well, it is possible, by referring to this chart again, instead of sending a continuous television signal back to the Earth, if we were merely to take one picture of a planet's surface and store this picture on, say magnetic tape, we could then send it back at a very slow rate which would involve only the narrow-band telemetry rates and thus conserve tremendous amounts of power.

Let me demonstrate or show you a few of the contemplated systems for accomplishing this sort of thing. In the center of this chart we have a satellite or a space probe which represents a similar system to the spinning cloud cover meteorology experiment that Mr. Cortright talked about yesterday. Here we have an optical system and a radiation detector, perhaps a photocell, which looks at a very small point on the planet's surface, and we use the spin of the vehicle itself to sequentially look at various points on the earth's surface. This sends to the earth a very slow picture and we would have to take these number of points and plot them, that is, put them down in their sequential order and reconstruct a picture of the planet's surface, a very simple but not a really satisfactory type of system.

A much more elegant system might involve a videcon camera which takes a picture of a large segment of the planet's surface. This picture information is stored on a magnetic tape recorder and this magnetic tape recorder can then be slowed up and the information played back very slowly to the Earth.

A third system might use a camera with film on a rotating drum. We would again take a picture of a very broad segment of the planet's surface. The picture would be deposited on the film. The film would be automatically developed and perhaps a facsimile scanner could look at this drum while it rotates and read off the picture very slowly and transmit this information back to the Earth. Incidentally we have here on the table a model of a videcon camera which might be used in a system such as this. It is a very recent development, and its weight has been reduced to something like 6 pounds, which makes it a very practical thing.

What can we accomplish in the way of power reduction by this technique? By these storage techniques we can go from this 10 billion watts to something in the order of 10 million watts, a very, very significant decrease in the power requirement.

The other area is the area of antennas. Remember, we said that in the case of this very crude technique we were considering an omnidirectional antenna, one that radiated in all directions. A very advanced vehicle might contain a steerable highly directional high frequency antenna, one which can beam most of the energy back to the earth. None would be lost in other directions. And again, being a very dignified vehicle, we have a television camera which can be pointed at a planet.

With systems such as this, where we can concentrate all of the energy in the direction we want, we can gain our most significant power reductions. This figure of 10 billion gets reduced to the order of a million watts. A later speaker, Mr. Heldenfels, will consider some techniques for getting antennas of this type into space.

A system which is perhaps still further in the future might involve a low frequency transmission system. There are certain advantages in going to low frequencies for the transmission of intelligence through space. However, we have the problem that low frequencies do not penetrate the Earth's ionosphere. This would require a relay satellite system outside the Earth's ionosphere to intercept these signals, change to a high frequency to bring them back to the Earth. This technique is quite a ways in the future.

Now what can we do if we combine several of these techniques? If we took the example of the nearly perfect receiver, the low noise

amplifier, and had an airborne antenna of the type I just described, we could get a continuous television picture in real time, that is an instantaneous picture from Mars with 10,000 watts, a large amount of power but not an unthinkable amount of power.

If we were interested in only a single picture and we combined the perfect receiver, the low noise amplifier, the airborne antenna and the storage technique we get down to very nominal amounts of power on the order of 10 watts. So we see that there are a great many things which can be done.

RESEARCH AND DEVELOPMENT REQUIRED

To review the situation and point up the research and development areas that have to be looked at to accomplish deep space communications, we have mentioned the recorders that give us high speed storage and then low speed playback of the picture, the storage videcon, tape recorders must be developed, and the facsimile photographic process is a possibility.

The low noise amplifiers, the masers and parametric amplifiers must have further work done on them. Antennas—we need large ground antennas such as the model over on the other table, to intercept the signals on earth. That happens to be a model of our Goldstone antenna and it is a reasonable replica of the thing. It is approximately 85 feet in diameter. We need the airborne antennas to concentrate the energy to the earth. The low frequency communication and the use of a relay satellite system to get us through the earth's ionosphere is a possibility. We need high-powered ground transmitters to communicate from the earth to ths space vehicle. We must develop high efficiency transistors so that we can make maximum use of the power that we do place aboard the space vehicle.

Power supplies, of course, must be developed. The more power that we can carry, the further we can communicate, and these power supplies will probably take the form of solar and nuclear energy converters.

The last area down here, information theory, is one which is a highly theoretical area. It is one which promises still further reductions in the amount of power required. I would like to just briefly try to give you an explanation of what is involved here. It generally says this: That most of the information that we try to transmit is redundant or not really useful. How do we extract only the useful data and send it and forget about all of the data which is not useful? If we can accomplish this, then we can reduce the power required for communications much, much further.

To conclude, I would like to indicate what our present capabilities, for instance with the Goldstone station, are and what we would like them to be in the future. We have already demonstrated with Pioneer IV, that our Goldstone capabilities are in excess of 400,000 miles. By 1960 we must have the capabilities of communicating with interplanetary distances in the order of 40 million miles, and by 1962 we must have the capability of communicating with the solar system.

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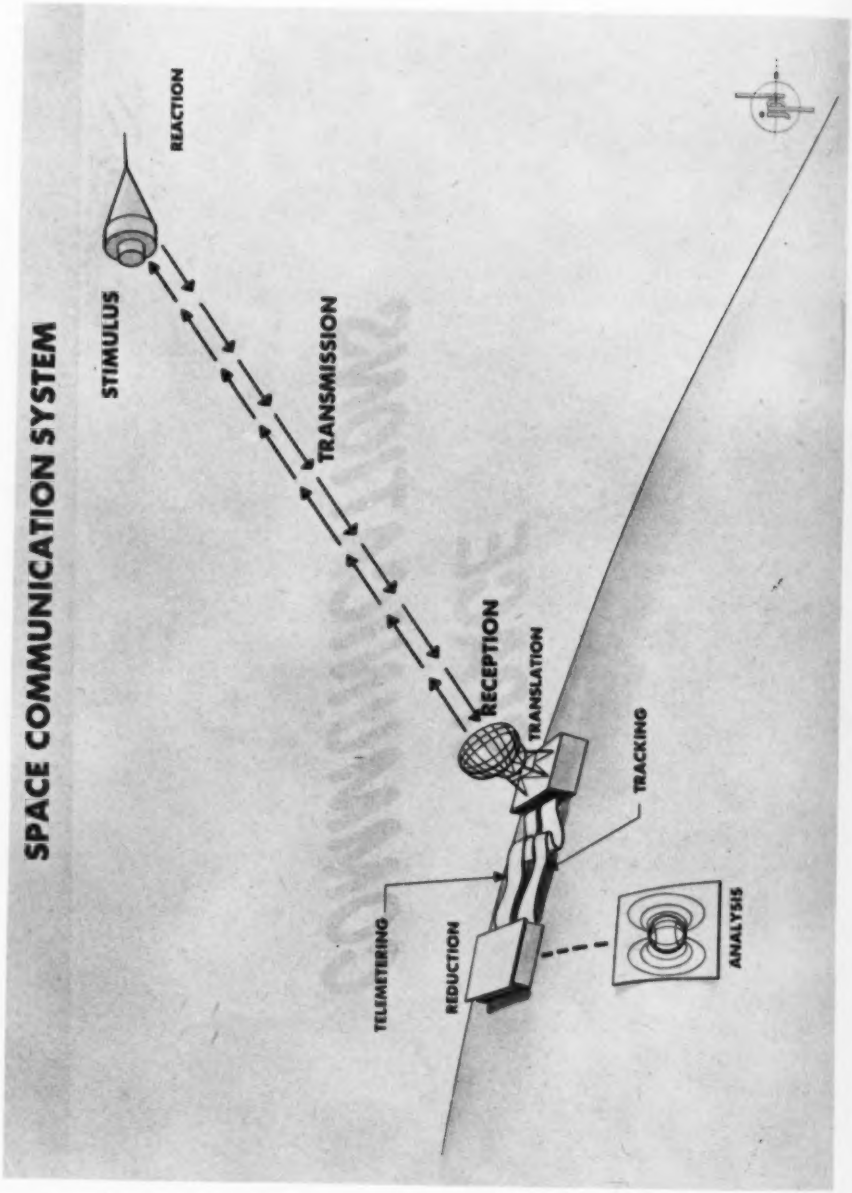
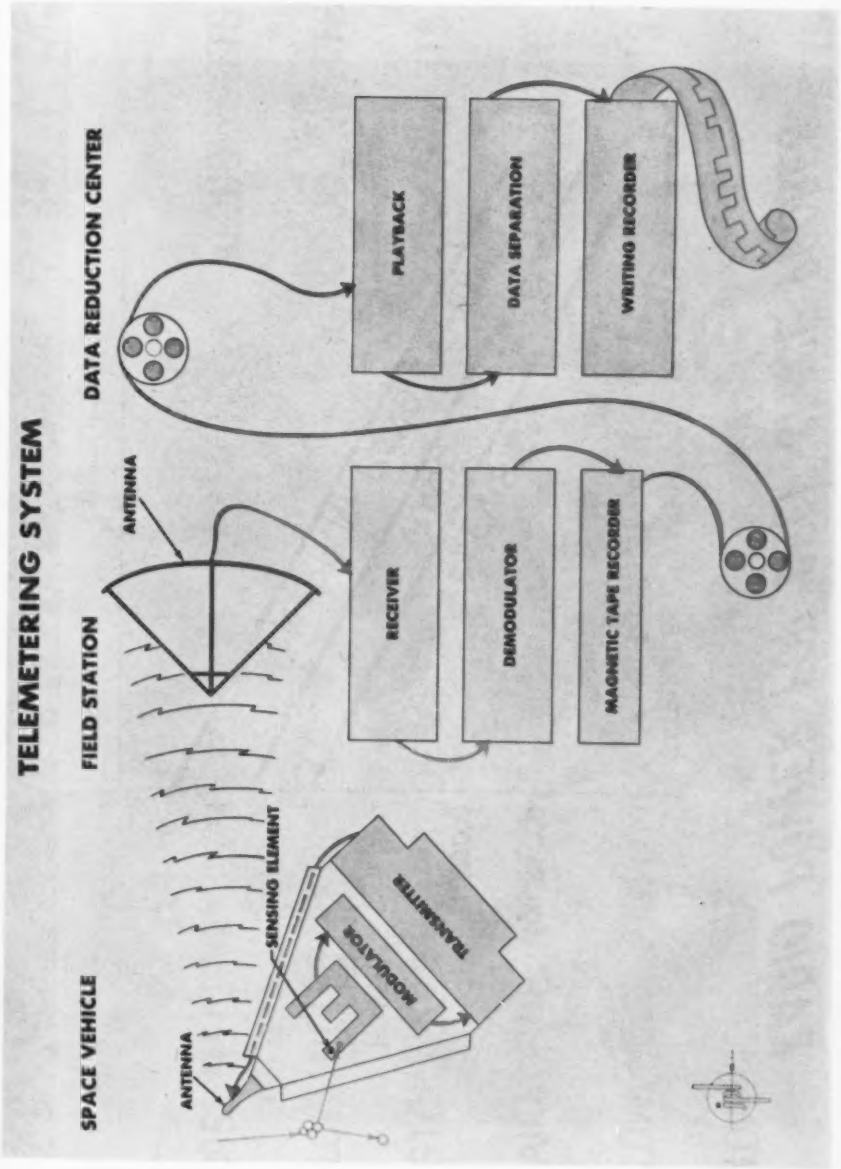
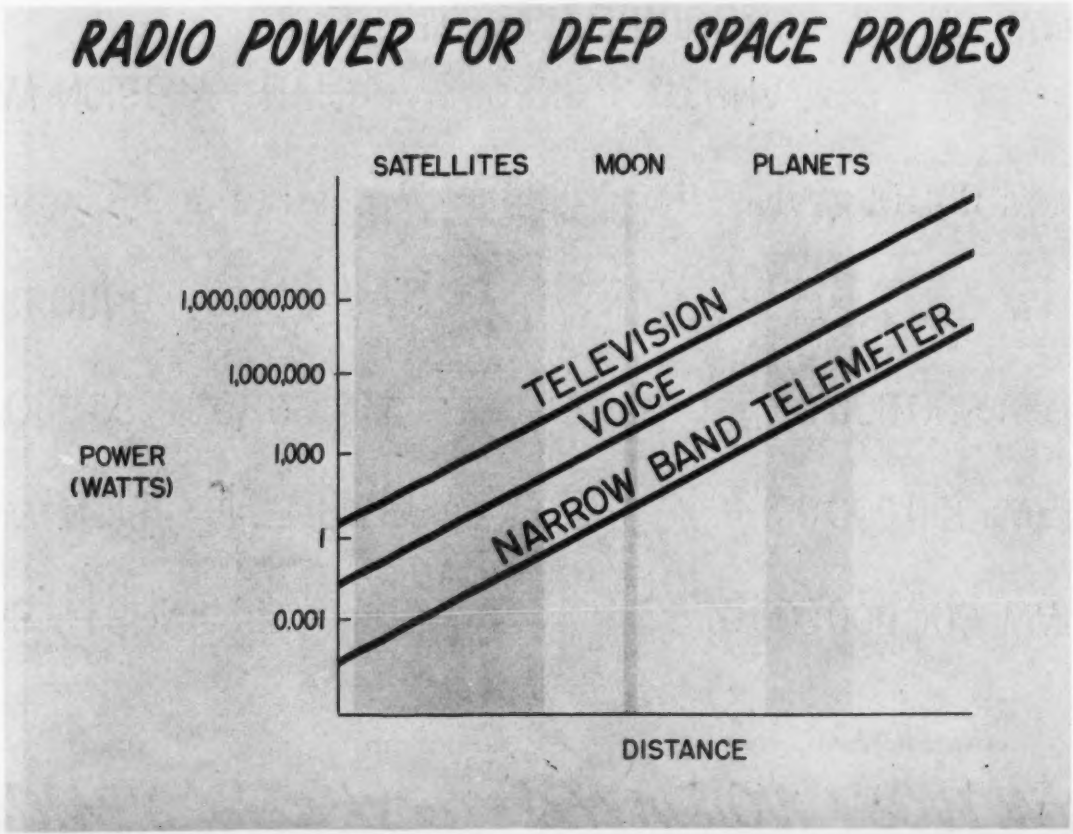
SPACE COMMUNICATIONS

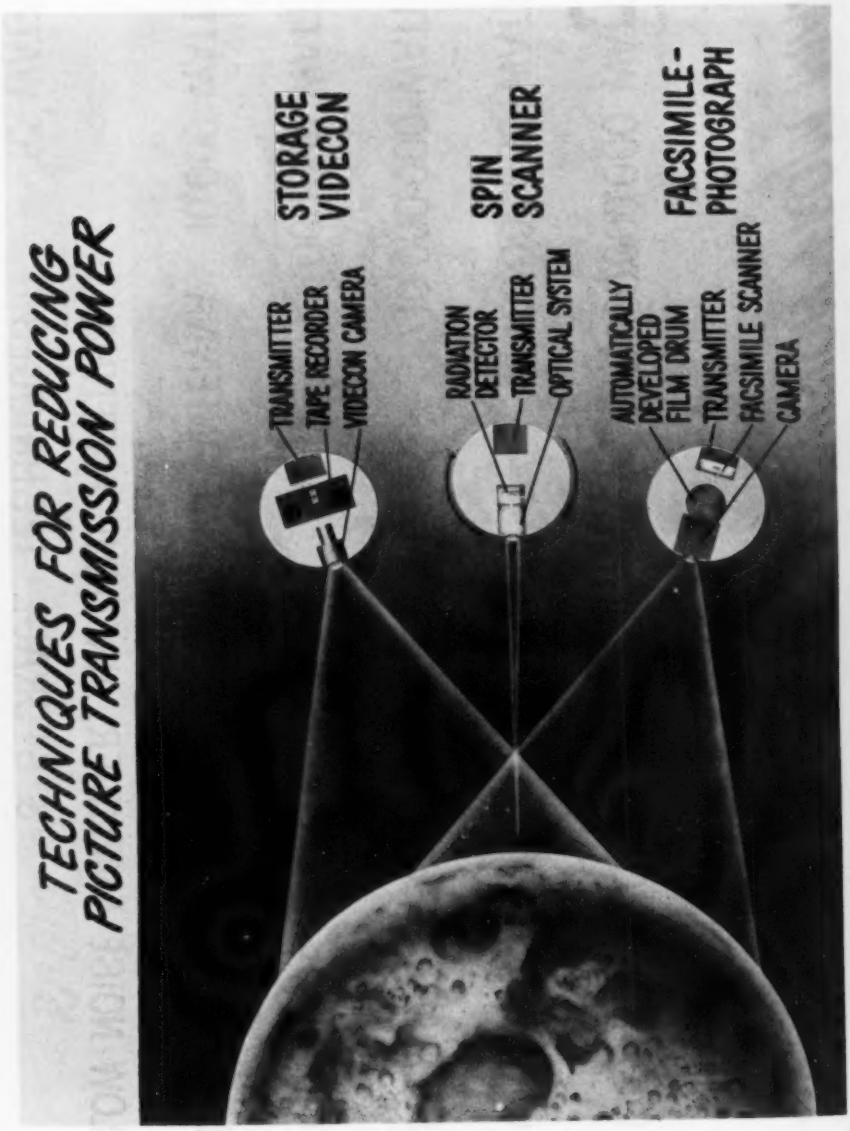

SPACE COMMUNICATION SYSTEM
STIMULUS
REACTION
TRANSMISSION
RECEPTION
TRANSLATION
TRACKING
TELEMETERING
REDUCTION
ANALYSIS


TELEMETERING SYSTEM
SPACE VEHICLE
FIELD STATION
DATA REDUCTION CENTER
ANTENNA
SENSING ELEMENT
ANTENNA
TRANSMITTER
MODULATOR
RECEIVER
DEMODULATOR
MAGNETIC TAPE RECORDER
PLAYBACK
DATA SEPARATION
WRITING RECORDER

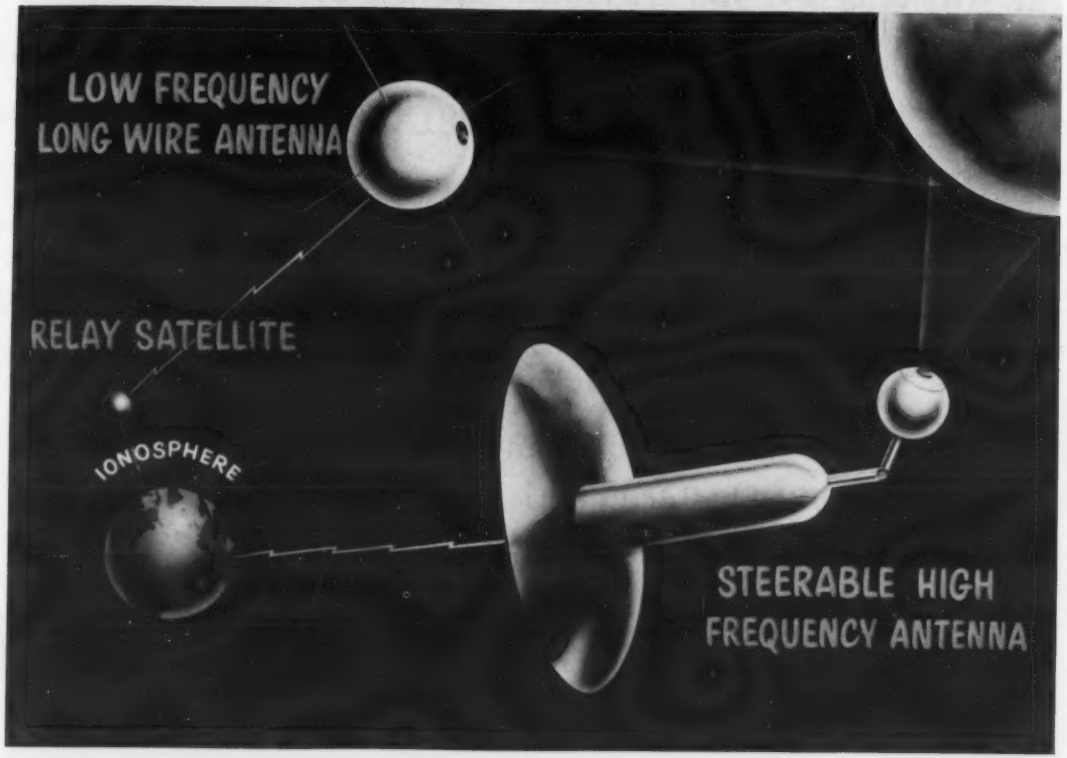

RADIO POWER FOR DEEP SPACE PROBES
SATELLITES
MOON
PLANETS
1,000,000,000
1,000,000
1,000
1
0.001
POWER
(WATTS)
TELEVISION
VOICE
NARROW BAND TELEMETER
DISTANCE

POWER REQUIRED - TELEVISION FROM MARS

1953 TECHNIQUES	10,000,000,000 WATTS
LOW NOISE AMPLIFIERS	100,000,000 WATTS
STORAGE TECHNIQUES	10,000,000 WATTS
AIRBORNE ANTENNAS	1,000,000 WATTS
LOW NOISE AMPLIFIER & AIRBORNE ANTENNA	10,000 WATTS
LOW NOISE AMPLIFIER, AIRBORNE ANTENNA & STORAGE TECHNIQUES	10 WATTS


TECHNIQUES FOR REDUCING PICTURE TRANSMISSION POWER
STORAGE VIDECON
TRANSMITTER
TAPE RECORDER
VIDECON CAMERA
SPIN SCANNER
RADIATION DETECTOR
TRANSMITTER
OPTICAL SYSTEM
FACSIMILE-PHOTOGRAPH
AUTOMATICALLY DEVELOPED FILM DRUM
TRANSMITTER
FACSIMILE SCANNER CAMERA

ANTENNA SYSTEMS FOR SPACE PROBES



DEEP SPACE COMMUNICATIONS RESEARCH AND DEVELOPMENT AREAS

RECORDERS, HIGH SPEED STORAGE-LOW SPEED PLAYBACK--STORAGE VIDECON, TAPE RECORDER, FACSIMILE-PHOTOGRAPHIC.

LOW NOISE AMPLIFIERS--MASERS, PARAMETRIC AMPLIFIERS, ETC.

ANTENNAS--LARGE GROUND ANTENNAS, AIRBORNE ANTENNAS

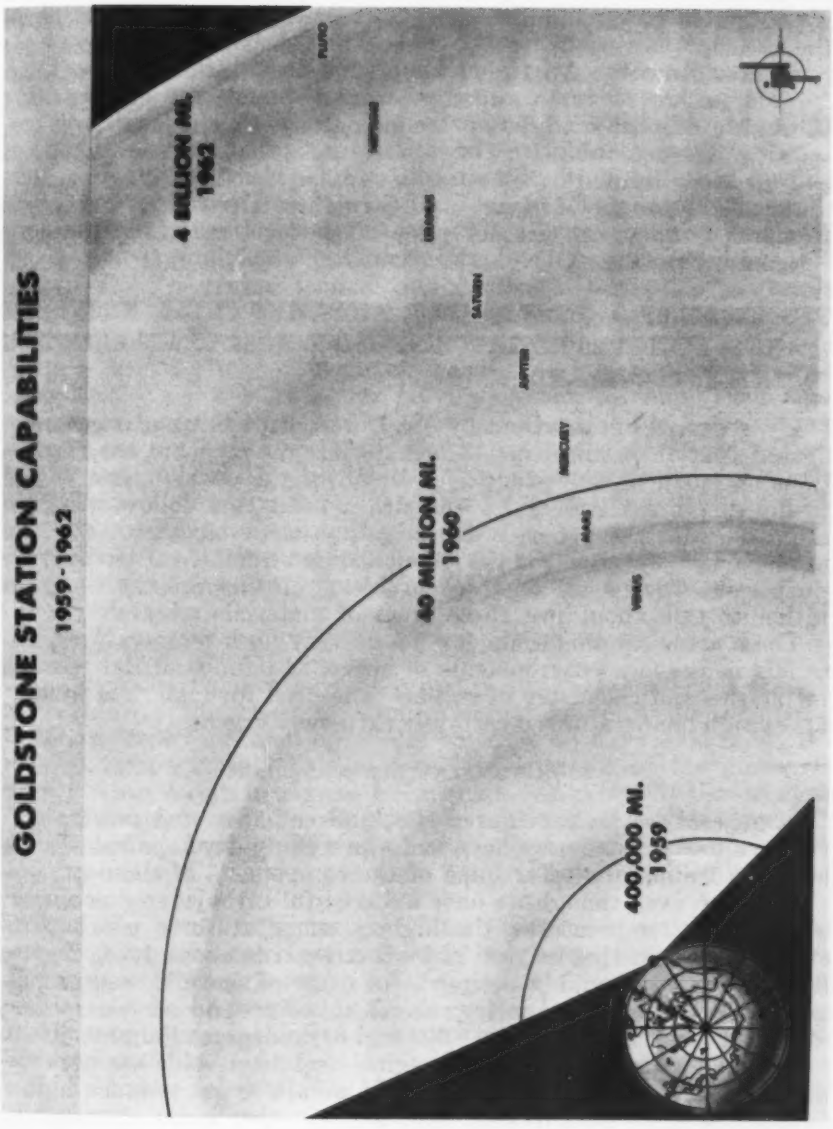
LOW FREQUENCY COMMUNICATION--USE OF RELAY SATELLITE OUTSIDE EARTH'S IONOSPHERE.

HIGH POWERED GROUND TRANSMITTERS.

HIGH EFFICIENCY TRANSISTORS.

POWER SUPPLIES--SOLAR AND NUCLEAR ENERGY CONVERTERS.

INFORMATION THEORY.



INFORMATION THEORY.

Senator STENNIS. You have quite a program there.

Mr. CORTRIGHT. I might mention, Mr. Chairman, that the last chart is predicated not only on the development of ground based equipment but boosters sufficiently large to put enough payload out there to carry a reasonable power supply. This is really the main limitation at the moment.

Senator STENNIS. All right, who do we hear next, sir?

Mr. CORTRIGHT. Now we change topics again, since we are running through a number of different technologies here, and switch to materials. The general history of engineering is that most developments end up being limited by materials. Mr. G. Mervin Ault, who is assistant chief for the Materials and Structures Division at our Lewis Research Center will describe some of the problems facing us.

Senator STENNIS. All right, Mr. Ault.

TESTIMONY OF G. MERVIN AULT, ASSISTANT CHIEF, MATERIALS AND STRUCTURES RESEARCH DIVISION, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO

Mr. AULT. As pointed out by Mr. Cortright, I think it is generally agreed that the achievements in materials research are the foundations of much of our progress in much of the development related to flight. In my talk and I am sure in some that follow it will be indicated that the progress depends upon achievements of the kind of materials we need for the particular environments. It isn't my purpose to review all of these problems at this present time, but rather to talk about just three areas of materials research.

These areas are materials for use at very high temperatures, materials in the new environments of space, and fundamental research in physics and chemistry of solids. The need for materials to operate at high temperatures is certainly extremely urgent.

HIGH TEMPERATURE MATERIALS

In general we have achieved the kinds of advanced powerplants we have today because we have had a preceding development of high temperature materials for some of the components of these engines.

However, even though we have a successful turbojet engine operating at high temperatures, the highest temperature to which parts are subjected in that engine at high stresses is about 1,800 degrees Fahrenheit. It would be desirable for many of the advanced propulsion devices we consider, such as chemical rockets and nuclear rockets, to extend use temperatures to 5,000 and 6,000 degrees Fahrenheit.

Now the backbone of the jet engine, as I have said, has been the nickel and cobalt base superalloys. If we are to get to much higher temperatures, we have to start emphasizing other kinds of materials. The reason for this is that the nickel and cobalt base materials, as shown here, melt at temperatures of about 2,700 degrees Fahrenheit. Obviously if we want to go to much higher temperatures, then we must use new kinds of materials that melt at much higher temperatures. Now one point of this chart is to indicate that there are quite a wide variety of materials available to us for study.

We usually prefer to use metals, because they are ductile, they can be bent and they can be formed. Fortunately, there are a few refractory metals available, as indicated here. Wherever we have an arrow it indicates the presence of that material. We have columbium, molybdenum, tantalum, and tungsten. Tungsten has the highest melting point and melts at about 6,100 degrees Fahrenheit. The materials shown below here by just the arrows are a different class and they might be characterized by calling them ceramics inasmuch as they are about as brittle as glass. These are the compounds of metals, the oxides, nitrides, borides and carbides of metal.

The highest melting point material we know is hafnium carbide that melts at over 7,000 degrees Fahrenheit. The important problems with these materials is that we have to change our technology. There is a more difficult problem in trying to melt tungsten at 6,000 degrees than in trying to melt and fabricate these other materials that we are used to at around 2,400 to 2,600 degrees Fahrenheit.

Within the laboratories of NASA we can currently melt tungsten. We are working with this metal and the highest melting of these ceramics. We are learning to fabricate them, to shape them and to produce them in forms that we can use. For example, I don't think I have seen until recently tantalum carbides in a shape that I can handle and work with. In addition to having extended our whole technology of working with materials by going to extremely high temperatures we have had to develop the techniques for testing these materials at these temperatures. Currently we can test at Lewis Research Center up to temperatures of 4,750 degrees Fahrenheit.

PROPERTIES OF HIGH TEMPERATURE MATERIALS

The next chart indicates some properties of these materials at high temperature. The chart will indicate that not only do these new materials have high melting points but they do have good strengths at high temperature. This is a plot of strength of the materials against temperature in degrees Fahrenheit, and generally the strength falls off in any material as we go up in temperature. This shows the strength of the best of the steels, here the best of the nickel or cobalt base superalloys, and here are some data we have obtained for pure tungsten.

Now this would indicate that if we needed a strength of 10,000 pounds per square inch, tungsten would have a temperature advantage of the order of about 1,500 to 1,600 degrees Fahrenheit over our best nickel and cobalt base alloys. As we continue our research and try to strengthen tungsten, which is a metallurgical problem, we should raise these strength levels appreciably. So it looks like we have before us a class of materials that will have good strength at very high temperatures.

I should hasten to add, however, that there will remain many problems in using these materials, even when we have them developed. Tungsten, for example, is about twice as heavy as nickel or cobalt. That means we have to limit its use in space vehicle propulsion systems. Another disadvantage I can emphasize by this simple demonstration I have brought along. This has a tungsten filament shown here, just a wire of tungsten, and by a battery inside I can pass an

electric current through this tungsten filament. Well, if we heat it up in air, tungsten oxidizes very rapidly. In fact, it just burns out. So it would be quite impossible to use tungsten in air—in fact, most of the refractory metals at high temperatures in an environment of air with our present knowledge. So it is a real important area of research to find out how to coat or protect these metals or to alloy them in some way so that we can use them in air at high temperatures. However, they are of considerable interest for other environments. For instance, in the chemical rocket or the nuclear rocket, the environment is not air.

In this part of the discussion I have tried to indicate that if we are to make great strides in going to higher temperatures that we need for many of our propulsion devices today, we are going to have to look at new classes of materials and extend our whole technology in materials research. Another area I wish to discuss is the problems of materials in the new environments of space. What will happen to materials in space? I think probably some of these have been mentioned already. The kinds of environments that concern us are low pressure, radiation in space, and the meteoroids in space.

LOW PRESSURE IN SPACE

The low pressure problem comes about from the fact that, of course, we have in deep space a perfect vacuum, in other words nothing at all. Now this can in many ways be an asset. For instance, we could make structures out of tungsten and use them in space. For example, the electric light bulbs that we have here, are tungsten filaments operating at 3,500° F. in a vacuum or in a neutral atmosphere.

So a host of new materials might be used at high temperatures in space. However, the problems that we encounter are generally due to this low pressure phenomenon. We are familiar with the fact, that liquids evaporate very rapidly, and as we raise the temperature they go off more rapidly. Well, in fact solids evaporate too. Let me take a specific case and talk about this space vehicle that you have seen in previous charts and talk about the radiator. This is a thin sheet metal device that might be 50 feet wide by 200 feet long. Here is a cutaway view to indicate the metal structure of this radiator. The problem here is that the atoms leave the surface at a very rapid rate at high temperatures.

For example, if we were to use nickel at 1,900° F. to take an extreme example, we would lose half the thickness of our radiator in 1 year.

Now for many applications we would like to use materials for much longer than that. In the case of metals there are solutions to this problem. In the case of palstics that we might like to use in space or some of the ceramic compounds that I mentioned earlier, this is a serious problem that needs much more research and understanding before we will know which of these materials can be used to fabricate high temperature space vehicles and components.

RADIATION IN SPACE

The second problem is that posed by the radiation in space. This is indicated schematically here again, that particles in space such as cosmic radiation are always impinging on our materials, and in sufficient doses or quantities they can cause material damage. Another kind of radiation that we are concerned with is the ultraviolet from the sun. Now on earth we are protected from most of this radiation by our own atmosphere, but in space the intensities go up.

However, in present appraisals of that problem it appears that metals will not be particularly harmed by the kind of radiations that we will encounter in space. It is indicated that some of the plastic-type materials or transparent windows may be darkened perhaps over a period of years by this kind of an environment, but there seems to be no reason that the radiation should be a serious deterrent to space travel from the standpoint of what it does to materials.

METEOROID IMPACT

The third class of environment in space that I want to talk about is meteoroids. These are the particles that travel in space at very high velocity. I find that Mr. Heldenfels who is to follow me and talk about aircraft or spacecraft structures was planning to give you some information on this subject so I will leave this to him. Actually, this is probably the most severe environment problem we have for materials in space.

Senator STENNIS. Which one is the most severe, do you say?

Mr. AULT. The meteoroids, meteoroid damage, impact of particles in space upon a structure such as a thin sheet metal radiator. And Mr. Heldenfels I think will discuss this more fully.

FUNDAMENTAL MATERIALS RESEARCH

Another area I wanted to mention is fundamental research into the physics and chemistry of solids.

For generations metallurgy, the art of making materials, has been almost a static art handed down from generation to generation. It has only been within the last 20 years that we have really begun to accept the fact that the properties of materials are dependent upon the arrays of atoms that make up the materials structures. Now once we can build our materials research upon a foundation of science, then progress should certainly be more rapid.

I would like to illustrate just one kind of an example here. The theoretical physicist doing research in physics of solids many years ago calculated the theoretical strength of a material. What he did was consider it as rows of atoms, calculate what energy it would take to pull them apart and he calculated strengths for materials that were to 20 to 100 times as great as we ever achieved in real materials that we use for construction.

Well, this has fostered a search for the kinds of materials that might really have this phenomenal strength. Here is a plot of the strength of pure iron and finally we get down to the size of whiskers. What we show here is the strength on a unit basis, strengths in pounds

per square inches in a cross-sectional area against diameter of specimen.

Pure iron in large specimen sizes, bar stock size, might have strengths of the order of 40,000 to 50,000 pounds per square inch but as we go down in diameter and finally approach this material we now call a whisker; these are little fibers that have a diameter of about one twenty-fifth that of a human hair; we measure strengths of 2 million pounds per square inch.

So it has finally been found that there are some kinds of materials available that approach the theoretical strength calculated by the physicist. The reason for this strength is believed to be that in real materials in this atomic area we have imperfections. If we have a row of atoms missing we call that a dislocation, and dislocations are sources of weaknesses in material. It is believed that these little very delicate whiskers are perfect crystals, the first time in nature we found a perfect material and that is why we are getting phenomenally high strengths. Of course, it is a problem of applied materials research now to see how we can put these whiskers together to make structures, solid bodies that might have really very high strengths. I think it would be difficult to say too much in support of this whole area of fundamental research in the physics and chemistry of materials.

This concludes the areas which I wanted to discuss. It was my purpose to bring your attention to the problems of finding materials at very high temperatures in some avenues we have ahead of us, the problems of using materials in the environment of space and lastly to comment on the problems of fundamental research. I think it is apparent that to solve many of the materials problems ahead of us will require a tremendous amount of effort by a variety of very competent scientific people.

Thank you.

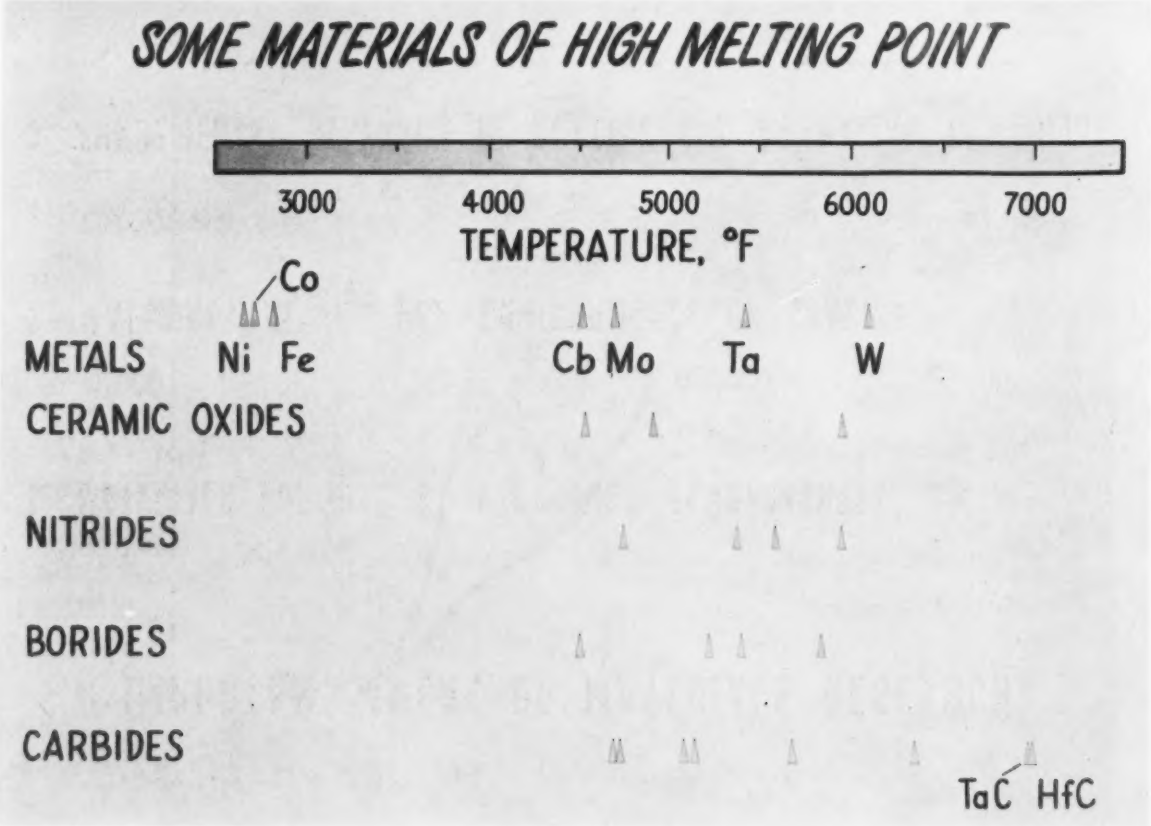
MATERIALS

IMPORTANT AREAS OF MATERIALS RESEARCH

1. MATERIALS FOR USE AT VERY HIGH TEMPERATURES

2. MATERIALS IN THE NEW ENVIRONMENTS OF SPACE

3. FUNDAMENTAL RESEARCH IN PHYSICS AND CHEMISTRY OF SOLIDS


SOME MATERIALS OF HIGH MELTING POINT
3000
4000
5000
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TEMPERATURE, °F
Co
METALS
Ni
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Ta
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CERAMIC OXIDES
NITRIDES
BORIDES
CARBIDES
TaC
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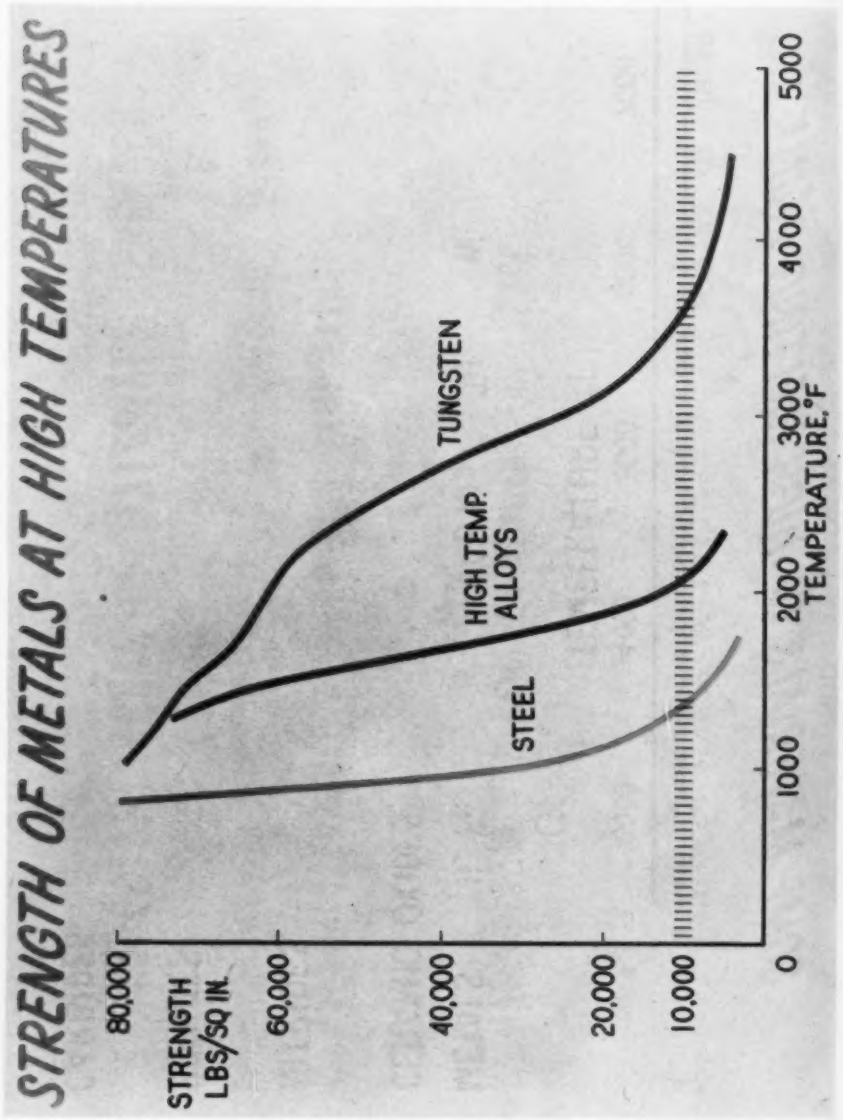
STRENGTH OF METALS AT HIGH TEMPERATURES
STRENGTH LBS/SQ IN.
80,000
60,000
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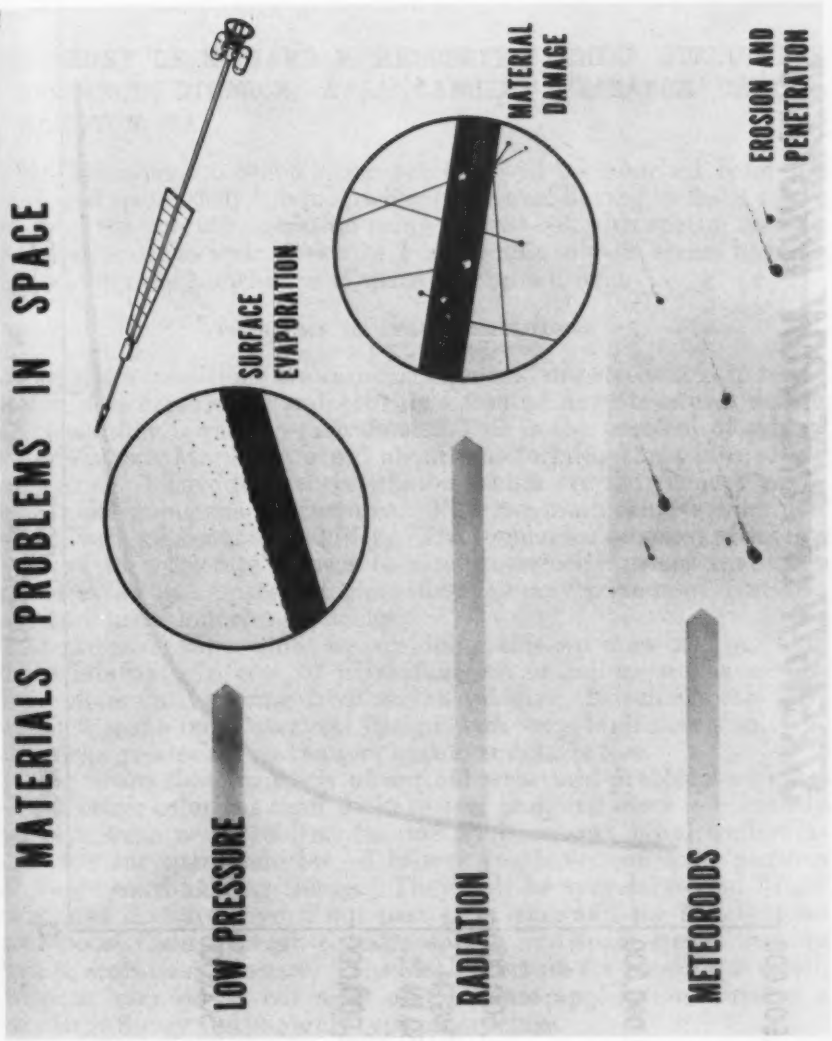
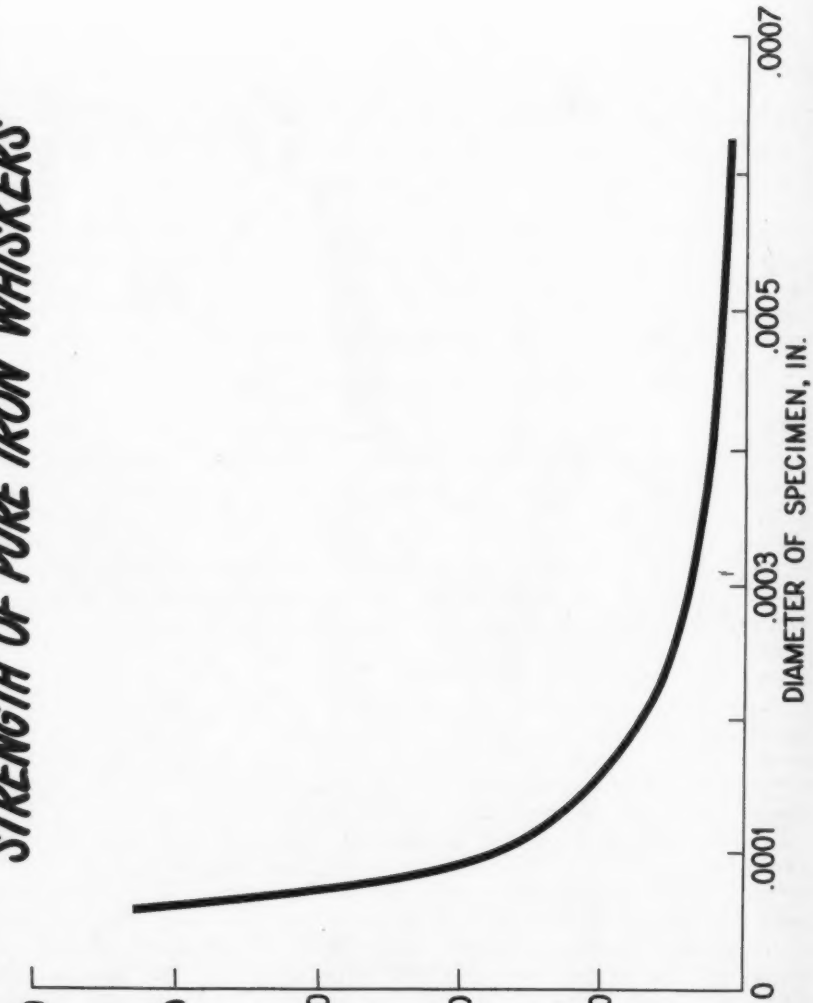
HIGH TEMP. ALLOYS
STEEL


MATERIALS PROBLEMS IN SPACE
LOW PRESSURE
SURFACE EVAPORATION
RADIATION
MATERIAL DAMAGE
METEOROIDS
EROSION AND PENETRATION


STRENGTH OF PURE IRON WHISKERS
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.0001
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DIAMETER OF SPECIMEN, IN.

Senator STENNIS. All right. Thank you very much. Who do you have next?

Mr. CORTRIGHT. The final speaker in this section on advanced technology is Mr. Richard Heldenfels, Chief of the Structure Research Division at the Langley Research Center.

Senator STENNIS. All right, Mr. Heldenfels. We are glad to have you, sir.

TESTIMONY OF RICHARD R. HELDENFELS, CHIEF, STRUCTURES RESEARCH DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. HELDENFELS. Some space vehicles will be launched from the earth and spend their life in space without ever having to make a safe landing, the landing operation being carried out with special reentry vehicles, so these space vehicles I am going to talk about have to survive only the launching and space flight conditions.

PROBLEMS OF SPACE STRUCTURES

The space conditions are rather unique and unprecedented in terms of our past experience, and provide a host of new structural design problems that I want to talk about. This is the problem of taking materials that Mr. Ault talked about and forming them into actual structures. I have listed here what we think are the primary problems in designing space structures. First, we much achieve minimum weight with maximum reliability. The tremendous amount of energy required to accelerate a mass to satellite velocity means that each pound saved in a space vehicle will save many pounds of fuel and structure in the launching vehicles.

At the same time while we are doing this we must not overlook the reliability. In case of a malfunction or failure we have very small chance of escaping from such a vehicle. To achieve this goal we must make our structural design with very high precision, precision to a greater degree than we have ever done before.

This means that for many of our old structural problems we must obtain better solutions than we have ever had, and more importantly we have some new problems because we have very novel configurations for our space vehicles. I believe you have seen some pictures of these weird-looking things. They will be very large and flimsy structures that are beyond our past experience and the fact that we must boost them through the atmosphere into space means that we have to erect them in space. The ideal structure for boosting is small, compact, very dense, but most of the space applications involve a very large flimsy and ungainly type of structure.

In addition they must be able to withstand this very unique environment that is encountered in space, something with which we have had little experience. There is no atmosphere there and the bodies in orbit are in a state of weightlessness. Even if we have a propulsion system taking us on an interplanetary journey the forces applied are extremely small compared with those that we are used to in aircraft and missiles.

Now these are all to our advantage as far as saving weight is concerned, but we are not familiar with them and we must design or devise new design concepts and design criteria to handle these adequately. In addition space is loaded with small particles called meteoroids, and also all kinds of radiation that are very harmful to the structure, and we must incorporate the proper shielding in our vehicle with the minimum amount of weight.

UNMANNED ERECTABLE SATELLITES

This chart shows one type of satellite that is proposed for the near future. It is unmanned and it is called erectable because it has to have this feature of being erected in space, as this rather unusual configuration could not possibly be put through the atmosphere at high speed without being destroyed. Its use is to relay communications or to make weather observations and this antenna and equipment in the body perform the functions of the satellite. This large solar energy collector collects the sun's rays to provide heat energy which is turned into electrical power to operate the machinery. In any event in any heat engine you have to reject a certain amount of the heat and this is radiated into space by the radiator.

We have been looking at two techniques for assembling this solar energy collector in space. In one case we have been looking at a mechanical system which operates very much like an umbrella. We want to have this thing in a small compact body when we boost it up into orbit and into space. We have a model here that we are working on. The actual structure will be much larger. It will be about 30 feet in diameter when it is erected. Once we get it up there we can erect it in this usable shape for our experiments. Now we are also looking into other techniques. In this case, the inflatable process, for which the structure is made of an assembly of tubes in which we place air and this erects it.

The first erectable satellite is this sphere which you have heard discussed before and it starts out as a very compact package like this, very good for boosting into space. A small cylinder of air like this will blow it up. I can't erect one for you here but this one has been erected prior to coming in. At the present time it has no air in it. It more or less supports itself, although as it sits around in the room, its material creeps and it will gradually collapse.

In this particular application in space the material from which it is made has a sufficient stiffness to hold it up but in other applications we have to look to foam plastics or the other things. In each case these structures are made from stuff that is a combination of metal foil and plastic, more commonly thought of as chewing gum wrappers. Because of the small forces, weightlessness, and absence of atmosphere it performs very well in space application.

MANNED SATELLITES

Let's turn now for a moment to manned satellites. We have a couple of them illustrated here. This is the Mercury capsule that you heard about this morning. It is not a space vehicle in the sense that I am talking about because this one must return to earth, and its

design is primarily dictated by reentry into the earth's atmosphere and it is more like a very high-speed airplane than a true space vehicle such as this large manned orbital laboratory over here.

This is one particular artist's concept of what it might look like. The primary structure problem here is providing a reliable cabin for the occupants. We can't afford to have this cabin leak at all because it contains a very precious atmosphere that we must maintain. We can't afford to have a meteoroid puncture it but in case we unexpectedly do get a puncture we can't allow it to have a catastrophic failure. We must stop the leak and go about our business. It looks as if these flimsy techniques we have for unmanned satellites are not applicable here and these will be more like our earthly structures but they are again very large and unique and one could not possibly boost this up in one piece. Consequently, one will have to develop means for putting it together in space. Now, one such proposal is that it might be made up of the tanks of the booster vehicles that are used to get it up there.

METEORITE DAMAGE

This chart shows what the surface of an orbiting laboratory might look like under a magnifying glass after it has been in space for a few years. It is all pitted with the impact of these meteoroids that are in space. These particles range in size from tiny specks of dust to fairly good size rocks. The frequency of their occurrence is greatest for the very small ones and decreases as the size gets bigger. They are traveling at extremely high velocities, up to 160,000 miles per hour so that when they hit the structure they can do substantial damage.

Now one way we can prevent puncture is to provide enough material in the structure so when it does get hit the particle will not penetrate.

But now in general for any structure that must remain in space for a long period this is impractical because of the high weight involved so we have to go to clever structural techniques such as providing light shields, which when hit by particle, break up into a number of impotent fragments which do not penetrate the primary structure.

We know that such an approach as this will work but we have not been able to work out the design details for two reasons. We don't really know enough about the meteors, their size, density, their actual occurrence, and we have not been able to generate these very high velocities in our ground test facilities.

A number of techniques such as gun-launched trajectories and the like are being developed and this is a sample, a piece of copper that is impacted by a tiny steel sphere traveling at 8,000 miles an hour. I have one of the spheres here. It is so tiny I have it in a piece of plastic. This little speck is somewhat larger than the speck that the typical meteoroid is but the energy this little piece possesed when it hit this copper disc was equivalent to the energy of a meteoroid that might hit this space laboratory about once a week.

So you see we have quite a serious problem that we need to know a great deal more about

Senator STENNIS. Did you say this illustrates an actual contact of some kind?

Mr. HEIDENFELS. A steel pellet such as in this plastic here was fired by a gun at 8,000 miles per hour and hit this piece of copper.

This is probably one of the most serious problems we have if the space structure is going to be up there a long time. We have two things facing us. First, we have to learn more about them and then try to duplicate the conditions here on the ground so that we can determine the best and lightest ways to prevent such punctures.

SPACE SHIP STRUCTURES

This last chart shows some futuristic space vehicles that might be used for an interplanetary journey such as going from here to Mars and return. It would take about 8 men along and require about 3 years.

There are two kinds, nuclear rocket propulsion and nuclear electric propulsion system and the configuration is primarily dictated by the type of propulsion required. The very large structures are rather unusual. Each weighs about 150 tons. This one is about 600 feet long, the length of a common ordinary ocean liner or a couple of football fields. Each has some unique features associated with its propulsion system. This system uses liquid hydrogen which must be kept in tanks at very low temperatures. Special shields are required to protect the tanks from solar radiation and the long length is required to protect the crew from radiation from the atomic power plant.

The unique feature of this system is a very large heat radiator which is about an acre in area so you can see when we get into this we have many unprecedented and unusual problems to design the lightest and best configurations of these structures.

To summarize my remarks, I say that we are faced with developing very novel and unusual configurations of structures that have to withstand a harmful, hostile, and unknown environment with very high reliability. We have to develop very precise methods for analyzing these structures and we have to find ways of coping with this very hostile and unknown environment. Thank you.

SPACE STRUCTURES

PROBLEMS OF SPACE STRUCTURES

MINIMUM WEIGHT WITH MAXIMUM RELIABILITY

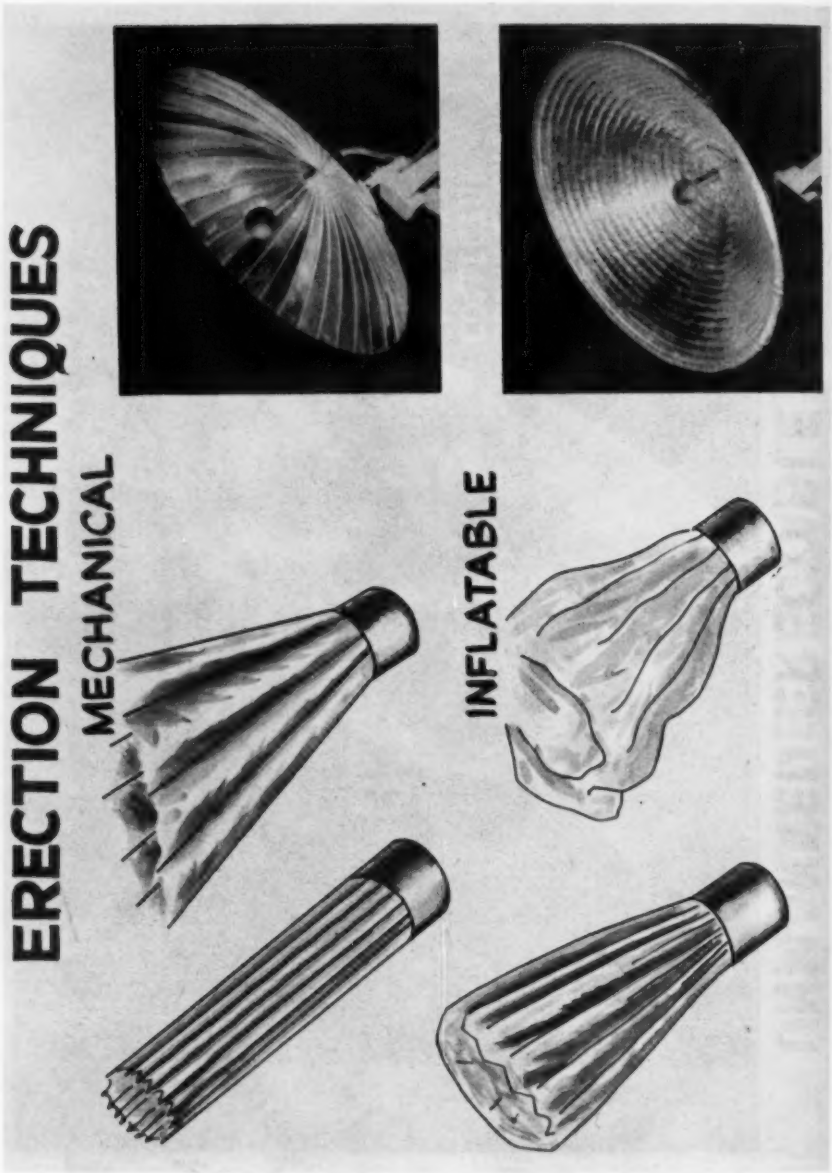
PRECISE STRUCTURAL DESIGN

- NOVEL CONFIGURATIONS
- LARGE AND FLIMSY
- SPACE ERECTABLE

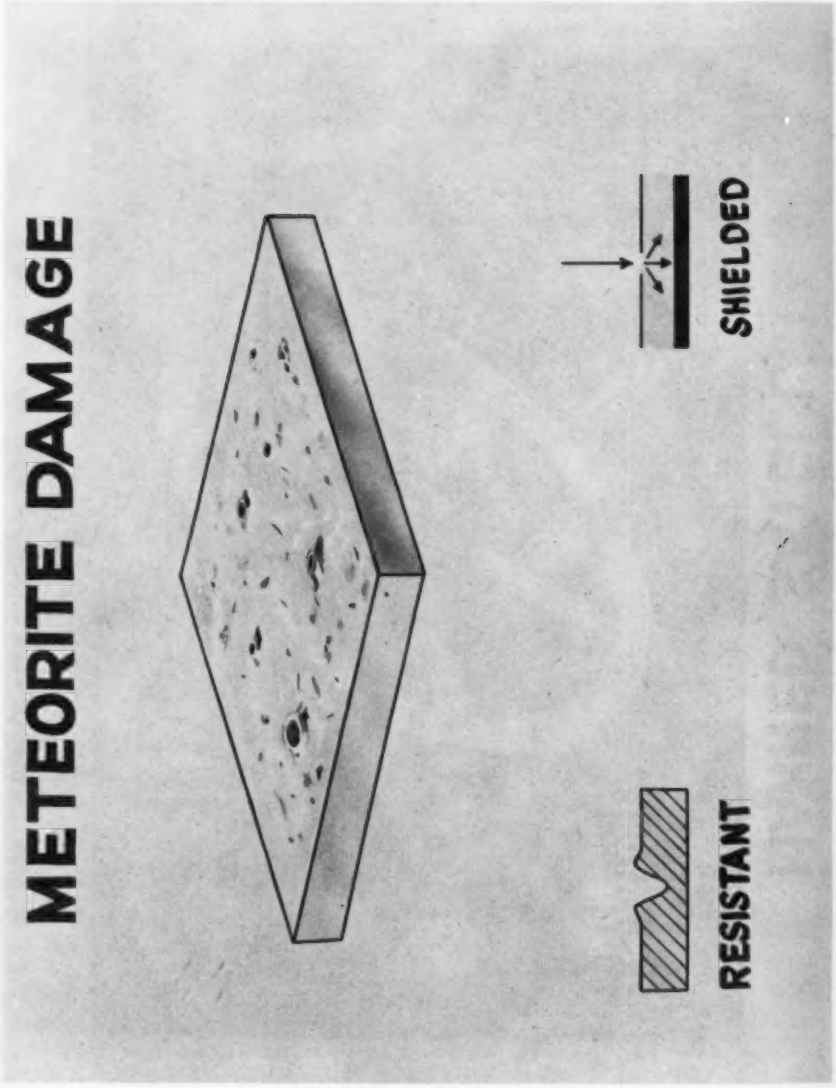
UNIQUE ENVIRONMENT

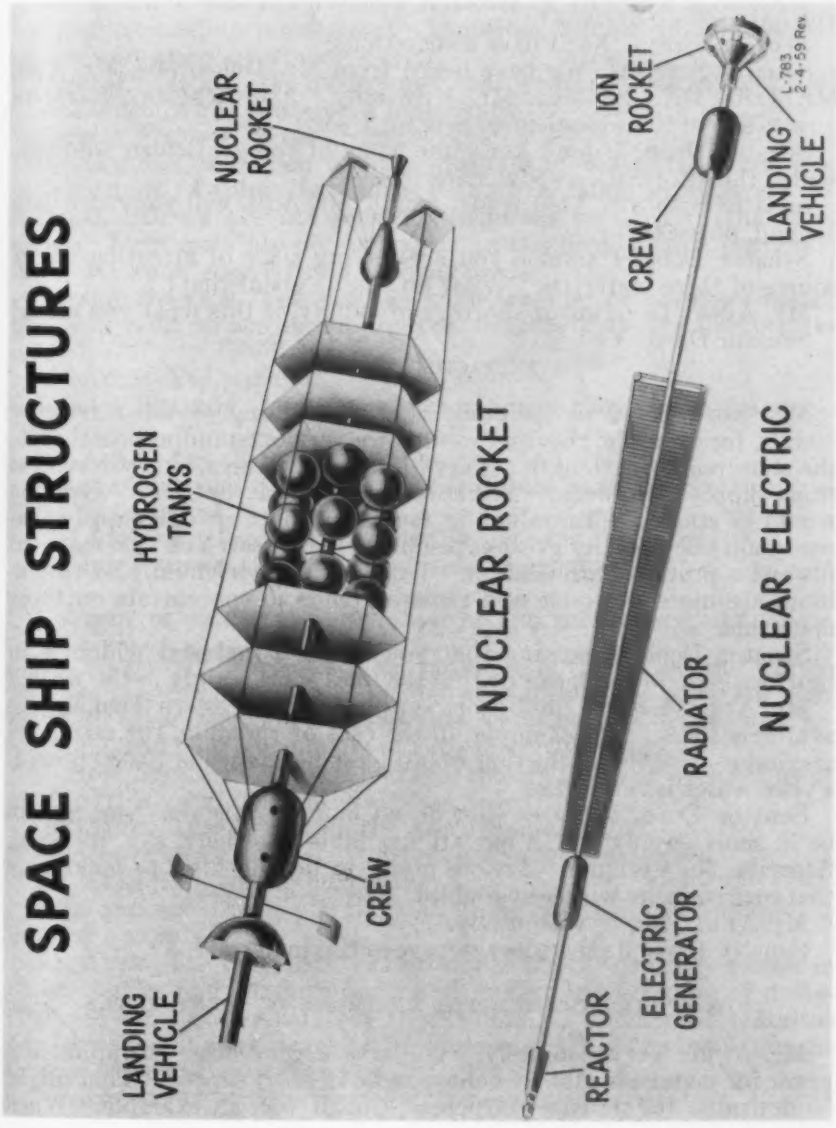
- NO ATMOSPHERE
- WEIGHTLESSNESS
- SMALL FORCES
- METEOROIDS
- RADIATION

UNMANNED ERECTABLE SATELLITE
SOLAR ENERGY COLLECTOR
HEAT RADIATOR
ANTENNA


ERECTION TECHNIQUES
MECHANICAL
INFLATABLE

MANNED SATELLITES


METEORITE DAMAGE
SHIELDED
RESISTANT



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Senator STENNIS. Thank you very much. This is a break, is it not, where we can have some questions?

Mr. CORTRIGHT. Yes; it is.

Senator STENNIS. Wait just a minute if you will. Mrs. Smith, do you have some questions?

Senator SMITH. No; I have no questions.

Senator STENNIS. We have heard from Mr. Heldenfels, Mr. Ault, Mr. Jaffe, Dr. Chapman, Mr. Milwitzky. Are there any questions now to any of these gentlemen, Senator Dodd?

Senator DODD. I don't know the name of the gentleman who presented the information about materials.

Senator STENNIS. That is Mr. Ault. Mr. Ault, will you come back around, please?

Senator DODD. I assume you are paying a lot of attention to the source of these materials. What do you do about that?

Mr. AULT. In terms of shortage of supply, is this what you mean?

Senator DODD. Yes.

REFRACTORY METALS

Mr. AULT. Yes; we definitely are. In talking of the refractory metals, for example, rhenium would be a very outstanding metal from the standpoint of strength at very high temperatures, but is in critical short supply. So we have minimized research in that area. Osmium would be similar. Tantalum, in fact, is in short enough supply that we would not consider great expenditures of research on this material toward a practical application. Tungsten, molybdenum, and columbium are more available and research tends to concentrate on those materials.

Senator DODD. Assuming that you found a material which is in short supply, do you mean by that the total short supply in the world?

Mr. AULT. I mean total short supply in the Western Hemisphere available to us. For example, in the case of rhenium, the estimated maximum possible production would be something like 10,000 pounds a year, which is very little.

Senator DODD. What do you do about materials that you find to be in short supply for us but are available elsewhere, say, in South America, for example. Are we going to do anything to make sure that such supplies will be available?

Mr. AULT. Oh, very definitely.

Senator DODD. Is there any storage of this material?

STOCKPILING PROGRAM FOR MATERIALS IN SHORT SUPPLY

Mr. AULT. Very definitely. We have a very large stockpile program for materials that we believe to be in short supply. That might be desirable for defense purposes. Cobalt was an example. When cobalt became very short, there was a tremendous exploration program to look for more cobalt, and a big stockpile program to make sure that we would have the quantities we needed for making the superalloys in the days of the turbojet engine.

Senator DODD. You work with the Bureau of Mines, I suppose?

Mr. AULT. I would say a lot of this is a responsibility of the Bureau of Mines, and we are, of course, in contact with those people, particularly in some of our very new problems on tungsten.

Senator STENNIS. May I just ask one additional question? Those two metals you referred to there as being so unusual and so necessary—what were the names?

Mr. AULT. I was emphasizing research on tungsten because it is our highest melting point metal. Tantalum, columbium, and molybdenum were also shown on my chart.

Senator STENNIS. Do you say now that we have those in stockpile?

Mr. AULT. We have tungsten in stockpile.

Senator STENNIS. What about the others?

Mr. AULT. Columbium is quite plentiful at the moment and also molybdenum. I think that in the case of tantalum supplies are not so good, but we are not pursuing vigorous research in that area either. I am certainly not an expert in the field, in this particular field. My knowledge is based upon my needs.

Senator STENNIS. Yes, but you know whether or not these metals that you refer to are in supply and whether they are likely to be needed.

Mr. AULT. Yes, sir.

Senator STENNIS. And also whether or not they are in the stockpile program.

Mr. AULT. Yes, that is right.

Senator STENNIS. So you say that tantalum is not in good supply—is not in stockpile?

Mr. AULT. No, I wouldn't want to be quoted in that way.

Senator STENNIS. Go ahead and restate your position.

SUPPLY OF TANTALUM QUITE LOW AMONG REFRACTORY METALS

Mr. AULT. My information on tantalum is this: That the world's reserves and the possible production of tantalum are quite low compared to other refractory metals that we might use. Tungsten, columbium, and molybdenum are in more plentiful supply.

Senator STENNIS. I believe you said though that you were not using much of this metal that was in short supply.

Mr. AULT. That's right, in the case of tantalum.

Senator STENNIS. You don't expect a prospective demand.

Mr. AULT. Not for big quantities.

Senator STENNIS. Do you think anything can be done about getting more of a supply?

Mr. AULT. The tantalum is so similar to other refractory metals in its properties and characteristics and in fact has a couple of disadvantages for high temperature applications. I understand tantalum has very specific advantages for electronics applications but I have no firsthand knowledge of this.

Senator STENNIS. Senator, I didn't mean to stop you.

Senator DODD. No, you didn't at all; your question raises another one in my mind. Are there any materials that are in short supply so far as we are concerned, those of us in the United States, located in any part of the world where it might be considered prudent and wise to try now to get all that we can? Are we doing anything of that nature?

Mr. AULT. I think that this program that you ask about, in other words making sure we have the quantity of metals we need in the case of some sort of an emergency is a very vigorous program and one that

stands, as I understand it, in very good shape at the present time. We are seeking out these metals and we are trying to stockpile those that we believe are necessary, and the stockpile quotas as I understand are being met very adequately.

COORDINATION OF BASIC METALS RESEARCH AND SUPPLY PROGRAMS

Senator STENNIS. May I follow up Senator Dodd's question there? The coordination, your basic metals research as well as the supply of those metals, is that coordinated now with the Department of Defense or any other related Government agency?

Mr. AULT. Yes, very definitely.

Senator STENNIS. Is there active coordination and cooperation on that?

Mr. AULT. Yes. For example, we have the NASA materials committee which has members of the military sitting on this committee reviewing the kinds of things you have heard from me about materials for the future and being aware of the kinds of materials we need in the problems of the future. I think it is reasonably well coordinated at the present time.

Senator DODD. May I ask another question?

Senator STENNIS. Yes, certainly.

Senator DODD. This is a great research program, from what we have heard—I suppose the information that you get causes you to change your views as you go along?

Mr. AULT. Yes.

Senator DODD. Is there any hazard that we might at some stage of this program come to a conclusion that a certain material would not be essential, and later on find out that we made a mistake? Is this the history of research and development in this field?

Mr. AULT. I think this is probably true to some degree, Senator.

Senator DODD. This would constitute quite a hazard for us, wouldn't it?

Mr. AULT. It seems to me that the mistake, if made, has been made in the other direction. In other words, take the metal, columbium. We decided that this metal was in critically short supply and we believed that we just could not get enough, so we diverted a lot of research away from the metal, columbium. Now because of this shortage there was tremendous exploration and great reserves of columbium were found and columbium now is coming back into the picture and it is an important material for research at high temperatures. So the mistake seems to be made the other way, that we think materials are short. Once a demand is created we tend to find more of them.

Senator DODD. Do you get a chance to be heard before the stockpiling authorities decide that a material which has been stockpiled is no longer essential to the stockpile?

Mr. AULT. This would not be my function. I am in research.

Senator DODD. I mean the agency.

Mr. AULT. I don't know whether I can answer that for sure except to cite an old example in the time of the National Advisory Committee for Aeronautics where the Defense Department gained quite a lot of advice from our materials committee as to the probable use of materials in defense industries and to help them decide which to stock-

pile. As to the status beyond that, I don't think I am in a position to answer. Maybe someone else here could.

Senator DODD. The reason I asked the question was that it occurred to me that somewhere I had heard about some material that was stockpiled, later disposed of, still later found to be very important and essential but it had already been disbursed, sold off, or something of that kind.

Mr. AULT. This is possible. I personally do not know of this example.

Senator DODD. Don't you think it would be wise to perhaps have somebody watching that and in close touch with the persons who do dispose of the stockpile material?

Mr. AULT. Certainly this would be wise. I think it is being done, however.

Senator DODD. I assume it is too.

Senator STENNIS. Mr. Ault, you spoke of being on the committee with the military. Do you also serve or does someone from your department serve on other matters, on metals with the military, whether it directly affects something you are using or not? Do they consult you? You said in effect that you consulted them, but do they consult you on all of these matters? When I say you, I mean your department?

Mr. AULT. Well, again I am not in the best position to answer that question.

Senator STENNIS. All right, let's let Mr. Cortright answer it if he can. If he can't, supply the answer later. We want that picture brought out. You are not in a position to know about those contacts. Do you have anything to say on it?

Mr. CORTRIGHT. I certainly would imagine that the metallurgical community is closely enough knit that the needs of one area become known to the others.

Senator STENNIS. But it doesn't always work out that way, Doctor.

Mr. CORTRIGHT. If you would like, we will supply a statement for the record on this matter.

Senator STENNIS. I wish you would make a personal investigation of just what the practice is, not only for your department but the military, not only how far you cooperate with them but how far they cooperate with you. It is a field that I don't know much about. I don't know that I am phrasing the questions correctly. But if I have made you acquainted with the problem, why I wish you would follow that up.

Mr. CORTRIGHT. Yes, sir, we will do that.

Senator STENNIS. And get us a statement on it.

(The following information was subsequently provided by NASA:)

The current Office of Defense Mobilization's stockpiling policy, expressed in ODM Order V-7 (1958) states:

"PROVISION FOR SPECIAL PROPERTY MATERIALS"

"Prospective needs for high temperature and other special property materials shall be considered on the basis of a 3-year period beginning not more than 2 years in the future. Estimates for requirements, therefore, shall be included in the computation of objectives when there are indications of reasonably firm minimum requirements. In this connection, arrangements shall be made for the regular availability of objective scientific advice to assist in such evaluations."

To help implement the above paragraph, the Office of Defense Mobilization asked the National Aeronautics and Space Administration to review this area on a semiannual basis and to inform ODM of developments which might affect the stockpiling and critical materials picture. The NASA Subcommittee on Power Plant Materials reviewed this area in October 1958 and found no areas worthy of special attention by the ODM. Frequent reviews of this area will be undertaken by the NASA Committee on Materials and by NASA staff members in the materials areas.

Efforts by this agency on conservation of strategic materials have been lessened considerably over the last few years by the nature of the change in weapons system requirements, which impose less demand on critical elements than the large-scale production of turbojet engines and other military devices in the period prior to 1955. Department of Defense recognition of this change in the logistics picture has led to the elimination of certain Department of Defense orders on conservation.

In summary, the NASA's present effort in critical materials is limited to a review of research developments which may lead to materials shortages and to bring these to the attention of responsible agencies, such as the Office of Defense Mobilization.

Senator DODD. This is one place we could help them perhaps.

Senator STENNIS. Yes. Senator Dodd, do you have anything further from any of these gentlemen?

Senator DODD. No.

Senator STENNIS. Do you have something further?

Mr. CORTRIGHT. No, Mr. Chairman, we don't. The next section will be handled by Mr. Richard Rhode. Mr. Rhode is Asistant Director for Research in the NASA.

Senator STENNIS. All right, Mr. Rhode. Will you and those that are coming now—if you gentlemen will stand up and be sworn—Mr. Campbell, Mr. Hubbard, Mr. Wilson, Mr. Lundin, and Mr. Rothrock.

You gentlemen will be sworn.

Mr. RHODE. Mr. William H. Woodward will substitute for Mr. Rothrock.

Senator STENNIS. Do you and each of you solemnly swear that your testimony will be the truth, the whole truth, and nothing but the truth, so help you God?

Mr. RHODE. I do.

Mr. CAMPBELL. I do.

Mr. HUBBARD. I do.

Mr. WILSON. I do.

Mr. LUNDIN. I do.

Mr. WOODWARD. I do.

(The biographical sketches of the witnesses follow:)

RICHARD V. RHODE, ASSISTANT DIRECTOR OF RESEARCH (AIRCRAFT OPERATING PROBLEMS, STRUCTURES, AND MATERIALS), NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Richard V. Rhode was named Assistant Director of Research (aircraft operating problems, structures, and materials) at NASA headquarters after the National Aeronautics and Space Administration was established on October 1, 1958. Previously he was Assistant Director for Research (aircraft construction and operating problems) of the National Advisory Committee for Aeronautics, the predecessor of the NASA.

Rhode is a native of Wisconsin. He earned a bachelor of science degree in mechanical engineering from the University of Wisconsin in 1925.

Shortly after his graduation, Rhode joined the NACA as an aeronautical engineer at the Langley Aeronautical Laboratory. In 1945 he was named Chief of the Aircraft Loads Division. He was transferred to headquarters in Washington in 1949. One year later he was appointed Assistant Director of Research (aircraft construction and operating problems).

Rhode is the author of numerous technical papers on gust loads and fatigues of airplane structures. He is a fellow of the Institute of the Aeronautical Sciences. He and his family live in Bethesda, Md.

JOHN P. CAMPBELL, HEAD, DYNAMIC STABILITY BRANCH, STABILITY RESEARCH DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John P. Campbell is head of the Dynamic Stability Branch of the Stability Research Division, NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1939 at the Langley facility.

Born in 1917 in Scottsboro, Ala., Campbell attended the U.S. Naval Academy for 2 years and then transferred to Alabama Polytechnic Institute where he was awarded a bachelor of science degree in aeronautical engineering in 1939.

Campbell joined the staff of the Langley facility as a junior aeronautical engineer in the preflight wind tunnel. He was appointed head of the tunnel in 1944, and was named to his present position in December 1958.

Campbell is a member of the Engineers Club of the Virginia Peninsula. He, his wife, and their two sons live at 27 Sir Francis Wyatt Place, Warwick, Va.

HARVEY H. HUBBARD, HEAD, ATMOSPHERE AND ACOUSTIC BRANCH, DYNAMIC LOADS DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Harvey H. Hubbard is head of the Atmosphere and Acoustic Branch of the Dynamic Loads Division, NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1945 at the Langley facility.

Born in Swanton, Vt., in 1921, Hubbard earned a bachelor of science degree in electrical engineering from the University of Vermont in 1942.

Hubbard was on the staff of the Radio Interference Laboratory of Westinghouse Manufacturing Co., East Pittsburgh, Pa., before joining the NACA at Langley as an electrical engineer in the Physical Research Division.

He was transferred to the Vibration and Flutter Branch in 1949, and was appointed to his present position in December 1958.

Hubbard is a major in the U.S. Army Reserve, and is a member of the Acoustical Society of America and the American Physical Society.

Mr. and Mrs. Hubbard and their three children live at 23 Elm Avenue, Newport News, Va.

HERBERT A. WILSON, CHIEF, UNITARY PLAN WIND TUNNEL DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Herbert A. Wilson is Chief of the Unitary Plan Wind Tunnel Division at NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, at the Langley facility in 1937.

Born in Inverness, Miss., in 1914, Wilson received a bachelor of science degree in aeronautical engineering from Georgia Institute of Technology in 1934.

Wilson joined the staff at Langley in the full-scale wind tunnel facility. In 1943 he was appointed head of the tunnel. He later was named head of the Langley group which pioneered the design of the unitary plan supersonic wind tunnel—a $15½ million research facility which is used by the Nation's aviation and space flight industry in the development of airplanes, missiles, and space vehicles.

Wilson is a member of the Institute of the Aeronautical Sciences and the Engineers Club of the Virginia Peninsula.

Mr. and Mrs. Wilson and their two children live at 3 Holly Drive, Newport News, Va.

BRUCE T. LUNDIN, ASSISTANT DIRECTOR, LEWIS RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Bruce T. Lundin, Assistant Director, Lewis Research Center of the National Aeronautics and Space Administration at Cleveland, Ohio, began his career at Lewis in 1943 in the Thermoydnamics Division.

During World War II he was engaged in heat-transfer research and investigations of the cooling characteristics of multicylinder liquid-cooled engines. At the close of the war, he became head of the jet propulsion research section which conducted some of the early research on turbojet performance characteristics on afterburners for turbojet engines, and on turbojet thrust augmentation by liquid injection.

In 1949 Mr. Lundin was appointed Assistant Chief of the Engine Research Division at Lewis, and became Chief of that Division, with responsibility for the supervision and direction of the full-scale engine research program in 1952. This program covered analytical and experimental research on full-scale turbojet and ramjet engines under simulated flight conditions, on automatic control systems for various types of engines, on jet engine exhaust systems, and on analytical studies of complete propulsion systems. He was Chief of the Propulsion Systems Division from 1957 until appointment to his present position in October 1958.

Mr. Lundin was born in Alameda, Calif., on December 28, 1919. He earned a bachelor's degree in mechanical engineering from the University of California in 1942. He is the author of the chapter on Ramjet Enginers in the Princeton Series on High-Speed Aerodynamics and Jet Propulsion. He is an Associate Fellow of the Institute of the Aeronautical Sciences, and was a member of the NACA Subcommittee on Engine Performance and Operation from its organization in 1950 until 1958, when the NACA became the nuceus of NASA.

Mr. Lundin resides at 3331 Metropolitan Parkway, North Royalton, Ohio, with his wife, Barbara, and their three children, Dianne, Robert, and Nancy.

WILLIAM H. WOODWARD, CHIEF, POWER PLANTS RESEARCH DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

William H. Woodward has been Chief of the Power Plants Research Division in the Office of Aeronautical and Space Research since the National Aeronautics and Space Administration was established October 1, 1958. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1943.

Born in Haverford, Pa., in 1922, Woodward earned a bachelor of science degree in mechanical engineering from Haverford College in 1943.

After graduating from college, Woodward joined the staff of the NACA's Lewis Flight Propulsion Laboratory, Cleveland, Ohio, where until 1949 he was engaged in engine research, including instrumentation and high-temperature materials.

In 1949, Woodward was transferred to NACA headquarters in Washington, D.C., where he was concerned with high-temperature materials, and lubrication and wear. In 1951 he was named Chief of the Propulsion Division, a position he held at headquarters until the NASA was established.

Mr. and Mrs. Woodward (the former Barbara Spangler) and their two children live at 912 McCeney Avenue, Silver Spring, Md.

TESTIMONY OF RICHARD V. RHODE, ASSISTANT DIRECTOR OF RESEARCH (AIRCRAFT OPERATING PROBLEMS, STRUCTURES AND MATERIALS), NASA

Mr. RHODE. I should perhaps say to begin with, Mr. Chairman, that the introductory remarks made by Mr. Cortright at the beginning of the most recent section of our program apply equally well to the balance of our program. I should like to concur in his appraisal of the importance of the research function.

As contrasted to the space development and operations function of our organization, this research of course is conducted for the pur-

pose of advancing the state of the art so we can make good the development of advanced flight vehicles of all kinds for the future.

A large part of the research of which we speak is conducted in the research centers of the NASA. These centers are located at Langley Field in Virginia, at Cleveland, Ohio, at Moffett Field, Calif., and at Edwards, Calif. Several of the presentations that you have already heard reflect the activity conducted in these research centers. The remainder of the program will be devoted exclusively to this activity.

Another point I should like to make is that NASA stands for National Aeronautics and Space Administration. This means that we have responsibility in the field of aeronautics as well as in the field of astronautics, and for this reason we have included aeronautics in our program. I think, sir, that you share this responsibility in that you are considering the authorizing legislation for the whole NASA organization.

The range of our interest in research matters extends from those things having to do with helicopters and other vertical takeoff and landing aircraft through supersonic aircraft, hypersonic aircraft, guided and ballistic missiles to the space vehicles that you have been hearing so much about.

With this much of an introduction I should like to call first on Mr. John P. Campbell, the head of the Dynamic Stability Branch of our Langley Research Center who will speak on the subject of vertical takeoff and landing aircraft.

TESTIMONY OF JOHN P. CAMPBELL, HEAD, DYNAMIC STABILITY BRANCH, STABILITY RESEARCH DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. CAMPBELL. Verticle takeoff and landing or VTOL aircraft is one that takes off vertically, changes from hovering to forward flight, cruises to its destination and then returns to hovering flights and performs a vertical landing.

TYPES OF VTOL AIRCRAFT UNDER STUDY

VTOL aircraft can take many different forms as you will see later but it is possible to group these aircraft into five basic types according to their means of propulsion. These five types are shown here on this chart listed in the order of their top speed capability, with rotor types at the low speed end, rocket types at the high speed end, and with propeller, ducted fan, and turbojet types in between.

For this presentation I am going to narrow the field down a bit at each end of the speed range. At the low speed end I am going to exclude helicopters because they represent a well-developed VTOL type which actually constitutes an entire aircraft field in itself.

At the high speed end I am going to exclude the rocket-powered spacecraft which take off vertically and perform soft vertical landings on the Moon or one of the planets for this type of machine has been covered in other presentations.

This discussion then will be concerned with propeller, ducted fan, and turbojet VTOL aircraft and with some of the rotor aircraft other than the helicopter. NASA research in the VTOL field has been

closely related to service interest in this field. In some cases basic or exploratory research by the NASA has resulted in promising new ideas for VTOL aircraft, and this information has been brought to the attention of the services and industry. Later at the request of the services we have performed the applied research required in the development of specific VTOL aircraft. A good example of this relationship between NASA and the services is in the development of the turboprop VTOL transport.

Some of this work is covered on the next two charts I have here. On this chart we have some VTOL research models that we have used for exploratory research in this field starting about 8 years ago. These two models over on the left are called deflected slipstream configurations because they have large flaps which deflect the propeller slipstream downward to produce the vertical lift for hovering flight. Our research has indicated that these are not very promising types for vertical takeoff and landing or VTOL operation because of the thrust loss incurred in turning this propeller slipstream downward with a flap. But they are good machines for short takeoff and landing or STOL operation.

This configuration at the upper right is a tilt-wing configuration, that is the wing and the propellers are in the position shown here for vertical takeoff and landing, and for cruising flight they rotate downward to the normal position. This is a good VTOL configuration, but it is not as good for short takeoff and landing operation as these configurations with the large flaps.

The model at the lower right represents a combination VTOL–STOL machine with a tilt wing and with flaps which can be deflected at low speed. This configuration combines the best features of these other configurations and appears to be a very promising combination VTOL–STOL airplane type. That is, they can perform both vertical takeoff and landing, and short takeoff and landing.

PROPELLER DRIVEN VTOL RESEARCH AIRCRAFT

Now the research that we have done with these and other similar models has resulted in the construction of the VTOL research airplanes shown on this chart. These airplanes are sponsored by the services for the purpose of obtaining preliminary information on the flyng qualities of VTOL airplanes. Research machines of this type are sometimes called flying test beds because they are simple and usually crude-looking machines intended only for research use.

Since they are less expensive than operational prototypes of military airplanes, they afford the services an economical means of obtaining flight research data on VTOL aircraft. These two machines at the top here are the Vertol tilt-wing machine and the Ryan deflected slipstream machine both sponsored jointly by the Navy and the Army. The configuration at the bottom is the Hiller X–18 tilt-wing machine sponsored by the Air Force.

We have worked closely with the services and the contractors in the design and development of these machines and at present we are assisting in the preliminary flight testing of this Vertol and Ryan machines. Later we will obtain these machines for use in flight research programs.

COMMERCIAL USES OF PROPELLER-DRIVEN VTOL AIRCRAFT

All of this work that I have mentioned with models and with airplanes is leading toward the development of what we consider is probably the most promising VTOL airplane, that is the turboprop VTOL transport.

In addition to the military interest in such airplanes there is also an increasing commercial interest in aircraft of this type. One possible operation of such a commercial machine is illustrated in this next chart. It would operate from a heliport located on a pier near the center of a city.

This is just one possible operation. Since a VTOL airplane of this type could have a cruising speed comparable with that of conventional turboprop transports, and since it could operate from "close in" airports such as this, it could obviously make a large reduction in the time required to travel from city center to city center.

The airplane of this type will cost a lot more to build and operate than a conventional transport because it will be about 25 percent heavier and it will require about twice as much power for a given passenger capacity.

ROTOR, DUCTED FAN, AND TURBOJET VTOL RESEARCH AIRCRAFT

Now let us turn from these propeller configurations for a moment and look very briefly at the other three types, the rotor, ducted fan, and turbojet types. NASA has done the same type of basic and applied research on these other types but I am not going to take the time to go into this research. I will just show you some of the configurations that are under study.

In this next chart we have three rotor configurations. At the upper left is the McDonnell XV–1 which has a rotor for hovering flight and a pusher propeller for forward flight. It is shown here mounted in the NASA Ames 40-by-80-foot wind tunnel for force testing. The configuration at the lower left is the Bell XV–3 tilting rotor converti-plane. The rotors are in the position shown here for takeoff and landing, and for the transition to cruising flight, the rotor shafts tilt downward so that the rotors serve as propellers. The machine at the right is a flying platform machine that the pilot controls merely by leaning in the direction he desires to go.

On this next chart we have three ducted fan configurations. A ducted fan might be considered a propeller with a ring or shroud around it. At the upper left we have the Doak tilting machine which is another service sponsored flying test bed the NASA is working on. The machine at the lower left here is an aerial jeep which the Army is very much interested in. This type of machine would have a low top speed less than 100 miles per hour but it should be simple and easy to fly and should be suited to flying at very low altitudes or in the "nape of the earth," as the Army people put it.

This configuration at the right is the Hiller flying platform which is flown in the same manner as the aerocycle I showed in the last chart. That is, the pilot just leans in the direction he desires to go.

This last chart shows 4 turbojet configurations. The machine at the left here is the Ryan X–13 which has a hook on the nose to engage this cable on its landing service trailer for vertical takeoff and

landing. Transition to forward flight is performed by tilting over from a vertical to a horizontal attitude.

Senator STENNIS. That is not planned for passengers, is it?

Mr. CAMPBELL. That is, I was just getting ready to say that from practical considerations the services now seem to prefer the configurations where the fuselage remains horizontal. Even the pilots apparently don't like this too much. But the service has been interested in these configurations such as the X–14 where the fuselage remains horizontal. This Bell X–14 has two small jet engines here in the forward part of the fuselage with some vanes at the tailpipe beneath the wing here to deflect the jet exhaust downward to provide the lift for hovering flight. After Bell completes its preliminary flight tests of the X–14, the NASA will obtain it for a flight research program. This model at the lower left here is a model of the Bell XF–109 airplane, an interceptor type. It has two jet engines in tiltable pods here at each wingtip. It also has two more jet engines in the fuselage at the nose and two more at the tail to help provide the vertical lift for hovering flight.

Shown at the right here is an artist's drawing of a futuristic configuration. We are studying this now in some exploratory research. It represents a mach 3 turbojet transport with its main propulsion engines and tiltable pods out here at the wingtips in the position shown here for hovering flight. This machine would also have a number of lightweight lifting engines mounted vertically in the fuselage and used only for takeoff and landing. When we consider the problems just involved in developing a conventional turboprop transport for mach 3 and then include these problems involved in developing this vertical takeoff and landing feature, it is apparent that machines of this type are still quite a ways off.

In conclusion I might point out that although the research to date has indicated many promising military and commercial applications for VTOL aircraft, much more work still needs to be done before we will have practical operational machines of this type.

VERTICAL TAKE-OFF AND LANDING
L-775

BASIC VTOL TYPES

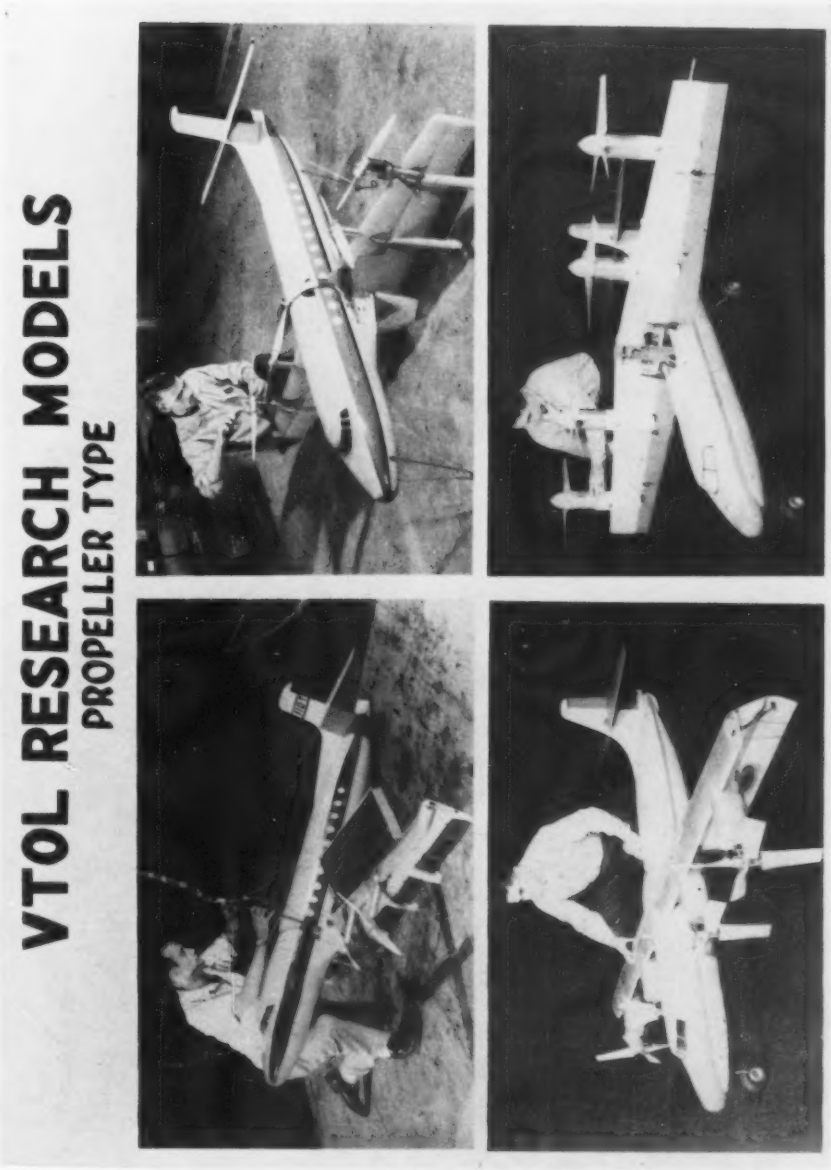
ROTOR

PROPELLER

DUCTED FAN

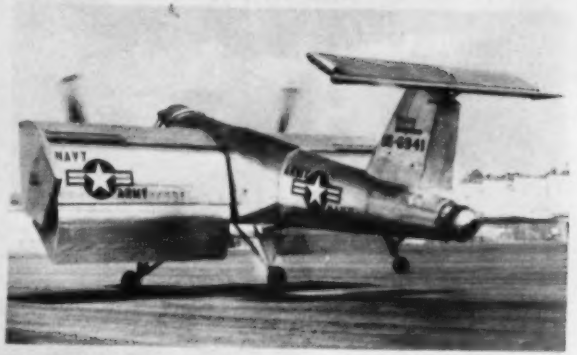
TURBOJET

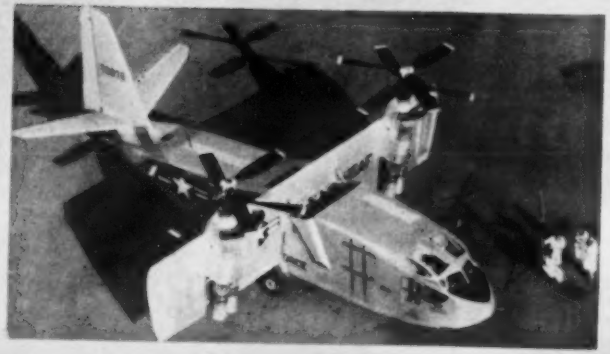
ROCKET


VTOL RESEARCH MODELS
PROPELLER TYPE

VTOL RESEARCH AIRPLANES

PROPELLER TYPE





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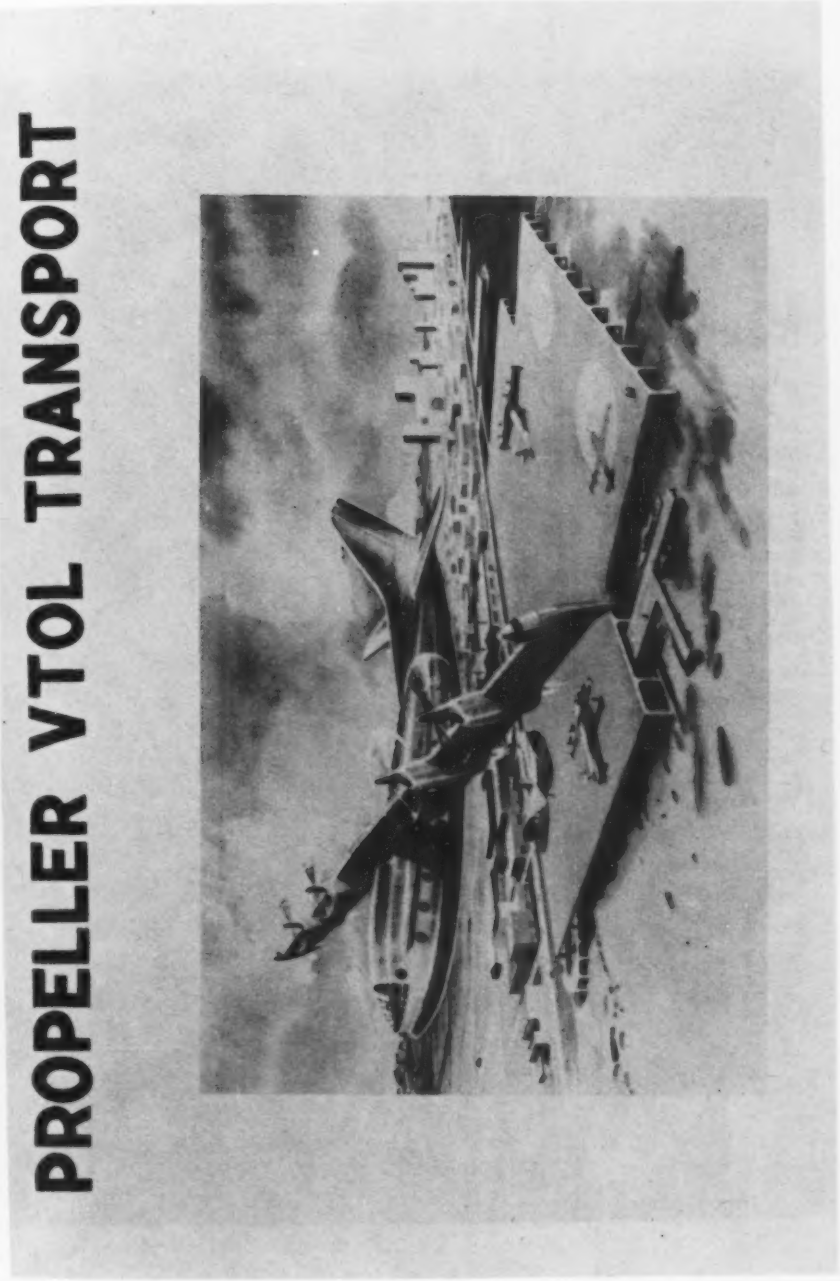

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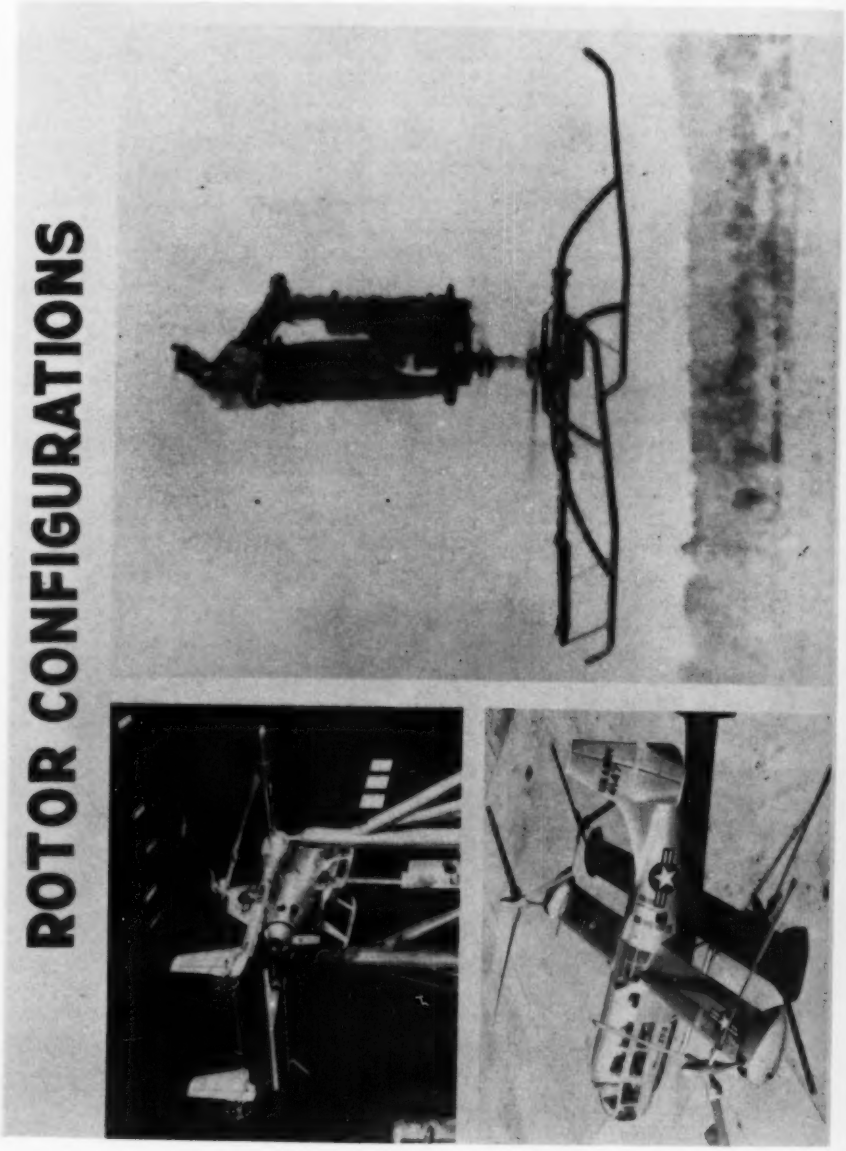
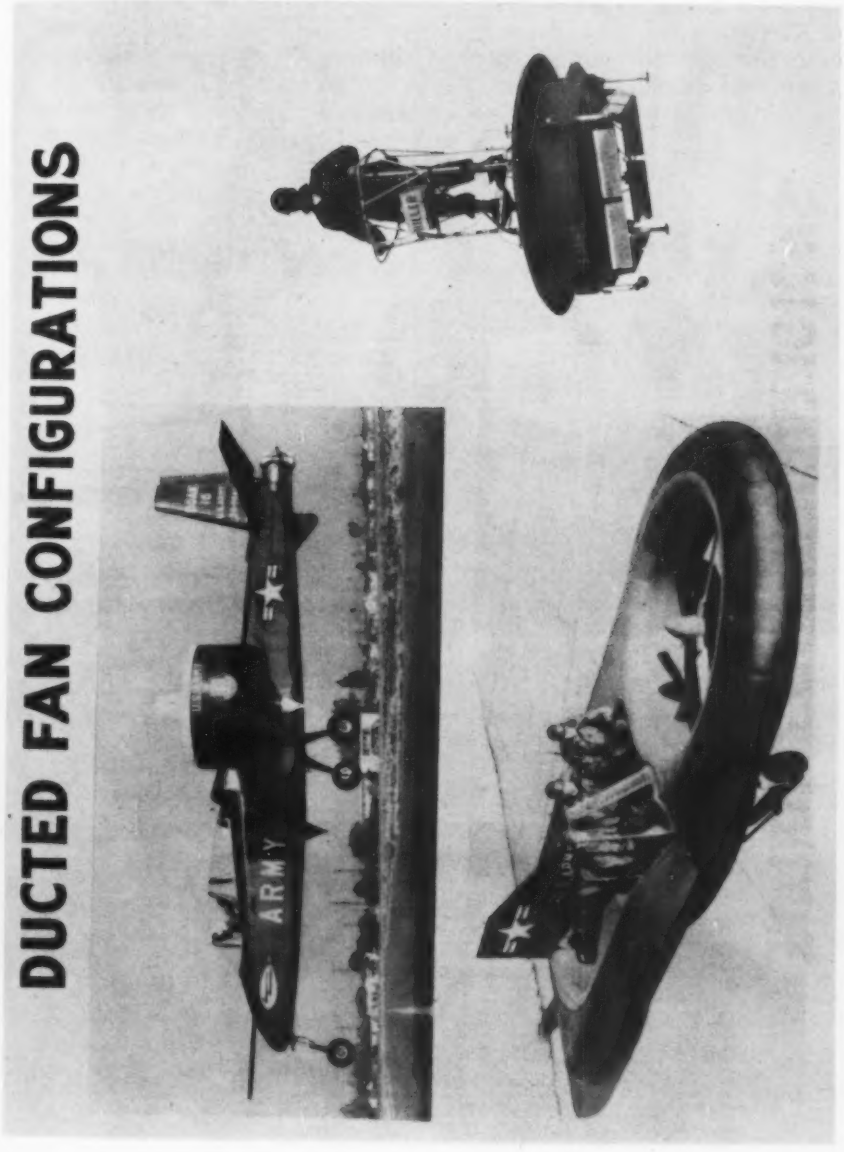
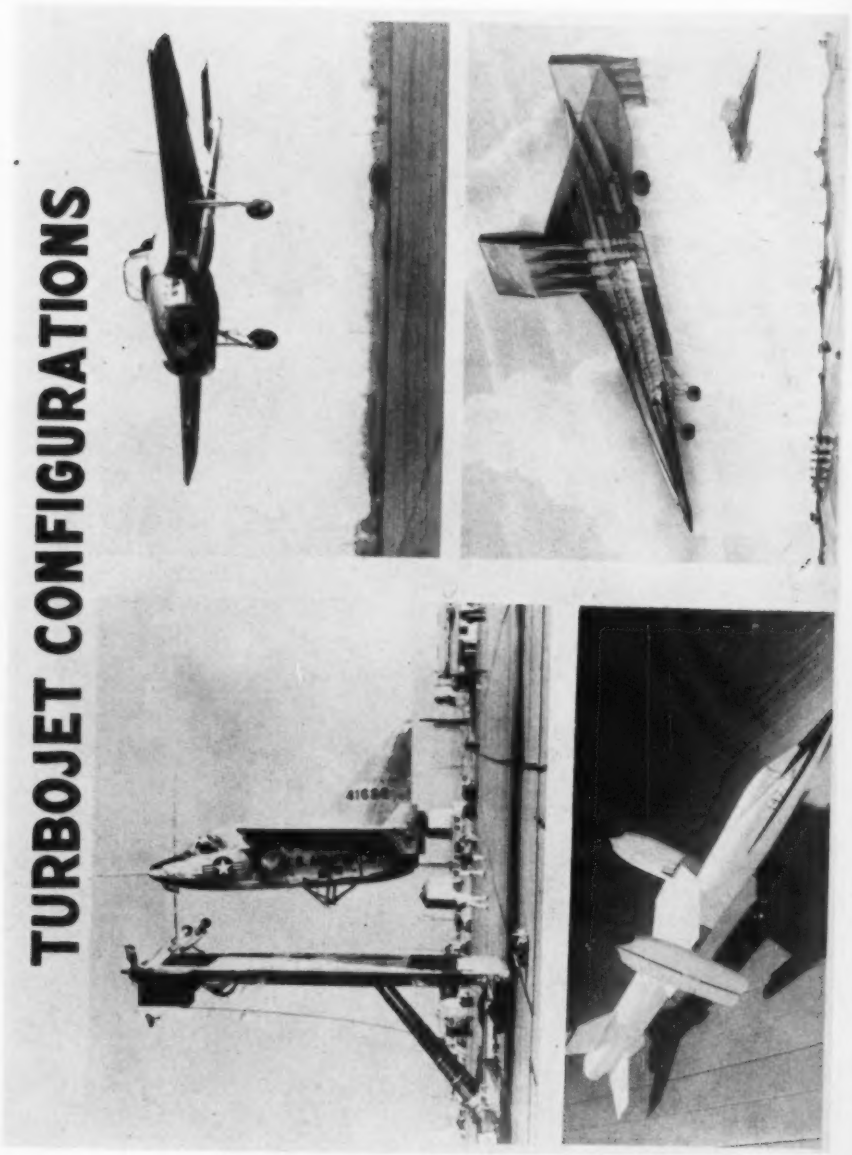

ROTOR CONFIGURATIONS


DUCTED FAN CONFIGURATIONS
ARMY


TURBOJET CONFIGURATIONS

Senator STENNIS. Just what do you mean, Mr. Campbell, when you say service sponsored?

Mr. CAMPBELL. The services buy the airplane. They are financed by the services. They, working with the NASA, determine——

Senator STENNIS. This was work that the National Advisory Committee for Aeronautics, the predecessor of NASA, was carrying out?

Mr. CAMPBELL. That's right. This is a continuation of that work.

Senator STENNIS. Just a continuation?

Mr. CAMPBELL. Yes, sir.

Senator STENNIS. Anything further you wish to say?

Mr. CAMPBELL. No, sir.

Senator STENNIS. Thank you very much, Mr. Campbell.

Who is next, Mr. Rhode?

Mr. RHODE. We are going to have Mr. Harvey H. Hubbard, sir. He is the head of the Atmospheric and Acoustic Branch of the Langley Research Center. One of the problems that affects all classes of vehicles and all classes of people is noise. He is going to talk about noise.

TESTIMONY OF HARVEY H. HUBBARD, HEAD, ATMOSPHERIC AND ACOUSTIC BRANCH, DYNAMIC LOADS DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. HUBBARD. I would just like to call to your attention that the sound that we perceive is a fluctuation of the atmospheric pressure in the vicinity of our ears and this is true whether we are considering desirable sounds such as music or speech or whether they are undesirable as in the case of noise.

Unfortunately noise is an unwanted byproduct of a great many important aeronautics and space operations and we are concerned about this noise because it may have a very profound effect on both the design and the operation of aircraft and spacecraft.

NOISE LEVELS

Before I get into a discussion of some of the specific problems that are facing us, I would like to introduce this first chart which should have some rather general significance, and will form a basis of the subsequent discussion. This was prepared in an attempt to attach some significance to noise levels. Noise levels are, for convenience, expressed in terms of decibels, and the louder the noise or the more intense the noise, the greater the number of decibels assigned to it.

The range of decibels that are of interest to us are indicated in this center column on the chart. The interval here, 20 decibels each, is equivalent to a factor of 10 in the pressure. The noise level in this room would probably be about here on my chart [indicating 70]. The noise level corresponding to pain in the human ear would be about 120, and you can see that we are interested in even higher pressures than this. As a matter of fact a value of 180 would represent pressures a thousand times as high as those that would cause pain in the human ear.

Over here I have indicated some sources and environments of noise, some of which are very serious. I would like to make the point here

that the ones that are on top of this list, the ones that generate the highest noise levels, are the sources that are of particular concern to us in our work.

Over here are some phenomena or results of noise exposure, and these include such things as speech interference, temporary hearing loss, malfunction of equipment, structure damage, and permanent hearing damage. I will have more to say about these later in the talk, particularly these more serious ones that are associated with the higher noise levels which in turn are generated by this particular rocket engine and jet engine.

JET ENGINE NOISE

The jet engine is a source of quite a lot of our noise troubles and probably the best publicized problem is the airport problem. I think you may know that the jet transport operations are restricted in some of the large population centers. One obvious solution to this problems would be to have an airplane that we could fly in a steep climb to a satisfactory altitude in as short a ground distance as possible. This solution has been used in the case of propeller-driven airplanes quite satisfactorily, but the jet transport airplanes, at least the present ones, are not designed in such a way that they can be operated in this manner.

So we have to look to other means of solution to this problem. Two solutions are suggested from the sketch on this next chart. We know from our research that some noise is generated inside the engine. We also know that the main source of noise is outside the engine, and it comes from this region here where the hot high-velocity gas mixes with the cool surrounding air. This results in a highly turbulent mixing region from which most of the noise comes. We know from our laboratory tests that the noise is very much a function of the velocity of the jet. The higher the velocity, the more noise. So this suggests that we ought to operate our engines at a lower jet velocity. This can be done up to a point but a lower velocity engine is a larger and a heavier engine, so we would have to pay a penalty in terms of weight.

Another approach to this would be to attach some gadgets at the end of the engine to operate in some way on this mixing region to reduce the noise, and this is another approach that is being actively pursued.

Senator STENNIS. Develop that—you say "actively pursued"; but it has been pursued a good while with no results; isn't that correct?

Mr. HUBBARD. I will elaborate on that a little bit, sir. I might mention that some of our companies are actually offering engines now that do operate at a lower jet velocity. Furthermore, mixing devices are installed on the engines of current jet aircraft and these devices do offer some more reduction.

Well, this is what these gadgets look like. These, of course, are research models but they do resemble quite closely some of those that are flying today. I might add here that these give a modest noise reduction and they have a modest performance penalty attached to them. If we were to expect considerably larger noise reductions with these types of gadgets we would have to expect to pay large per-

formance penalties. I might just mention that these operate on the principle of exposing as much surface area as possible of this high-velocity jet to the surrounding air so that it mixes rapidly.

Our research has shown one other version of these that seems to have some promise. This is mainly the use of an additional shroud which fits on the end of a nozzle such as this. It hastens the mixing even more and gives substantially more noise reduction. This shroud can be contracted and it thus has an acceptable penalty.

STRUCTURAL DAMAGE

Another problem that we have with jet engines is that of noise-induced structural damage. This is most serious on multiengine airplanes, and the damage occurs in regions such as I have shown here in the shading in the sketch. This is a very serious problem with all multiengine airplanes such as bombers, jet transports, aerial jet tankers. The kind of damage that we encounter is this type damage of the secondary structure of the airplane.

This happens to be from one of our bombers and it is the surface of a wing. As a matter of fact, one of the earlier versions of the multiengine bomber was capable of essentially destroying itself on the ground in a period of about 5 hours due to noise from the engines.

Senator STENNIS. You mean disintegration of the structure?

Mr. HUBBARD. Disintegration of the structure; yes, sir.

Now if we plot the life of a given structure as a function of the noise level, we find that at the higher noise levels we have a shorter life, and at the lower noise levels a longer life. Well, we know also that when the airpane is operating on the ground, that the surfaces of the airplane are exposed to higher noise levels than when the airplane is in the air. So this leads then to the conclusion that more damage in incurred on the ground than in the air. As a matter of fact, an hour of ground operations such as takeoff or ground runup conditions is the equivalent of about a thousand hours in the air.

Tens of millions of dollars have gone into the development of structures to withstand the intense noise loads, and this is an example, this sandwich type material is an example of a good type structure for intense noise loadings. However, we also know from experience that if a structure is exposed to higher noise levels than those for which it was designed, that we can have failures, and, of course, this is an example of a failure of a basically good construction.

Senator STENNIS. That exhibit you have there, is that from a bomber?

Mr. HUBBARD. Yes, sir. Now some of our missiles have been lost due to noise induced vibrations of some of the sensitive control equipment on board the missile, and this has led to an evolution of design of the electrical circuity. I have here a sample of the results of this study where the dangling wires and connections have been replaced with this type of assembly, and even some of the small circuit elements are imbedded in cards to minimize the effects of vibration.

Of course, the difficulty here is that on some of the larger installations these cards get large and then we have the vibration of the card itself which may lead to fracture and fatigue. This of course would interrupt the circuits.

BOUNDARY LAYER NOISE

So far we have talked about the problems encountered at low speeds with our jet aircraft. We are also concerned with some high speed problems now and in particular this chart deals with the boundary layer noise problem. The boundary layer noise results from a shearing action of the flow against the surfaces of the airplane, and this is most intense toward the rear of the airplane where the boundary layer is the thickest. We don't have much control over the generation of the noise so we have to supply sound treatment to the airplane to minimize the detrimental effects of it.

So my chart here shows the relative weights of material as a function of distance along the airplane, and this happens to be an airplane like a jet transport type, and we note that most of it, most of the weight has to be put in toward the rear where the boundary layer noise is most intense. This represents several thousand pounds of weight, which of course could be a sizable percentage of the payload of the airplane. This is put into it to protect the occupants of the airplane.

SONIC BOOM

Another high speed problem is the so-called sonic boom problem. An airplane in supersonic flight will generate a bow shock wave and a tall shock wave and these will extend to the ground and will sweep along and will sweep by an observer on the ground. The net effect here is a rapid change in the atmospheric pressure where each wave intersects the ground, and the ear responds to this rapid change in pressure as if there were an explosion, so that it senses an explosive-type sound.

Usually the ear would hear two of these as an airplane passes. These sound very much like thunder. If the airplane is a long way away it sounds like a faraway rolling type thunder. If the airplane is close by, it may sound like a very sharp crack, which is distasteful, and in the extreme can cause damage to light structures. Needless to say, research on all phases of this problem is going on at the present time.

SPACE VEHICLES

So far we have talked only about aircraft. If we are faced with the problem of manned space flight, then we also have some potentially serious noise problems there. Here I have indicated a space vehicle with a manned compartment here in its liftoff condition. The chart shows that the exhaust from the rocket motors is turned along the ground.

In this configuration, the main source of noise is the rocket engine, and this noise envelops the whole vehicle, as indicated by the noise contours. This part of the compartment, where the man is, is exposed to noise levels of 145 to 150 decibels, and this is sufficient to cause some damage on the structure if the exposure time is long. Also along this whole vehicle there would be some chance of structural damage. We are not only concerned with structural damage however.

In this case we are concerned also with communications with the occupant on the ground and this is difficult in the presence of intense noise fields. As a matter of fact, commuications for a vehicle like this would be rather difficult for about the first 2 minutes of the flight. This is due first to the intense noise from the rocket engines that lift off and then the noise from the boundary layer as the vehicle exits from the atmosphere.

FUTURE TRENDS

The question arises as we look to the future whether the noise problems of the future will be more or less severe than the ones that face us today, and an answer at least is suggested by this last chart. Here I have plotted the maximum noise levels encountered for various well-known powerplants as a function of calendar years, and we see that the slope of these curves is generally upward, that is, more noise is generated as time goes by and this of course results from the fact that we are constantly striving for more powerful propulsion systems.

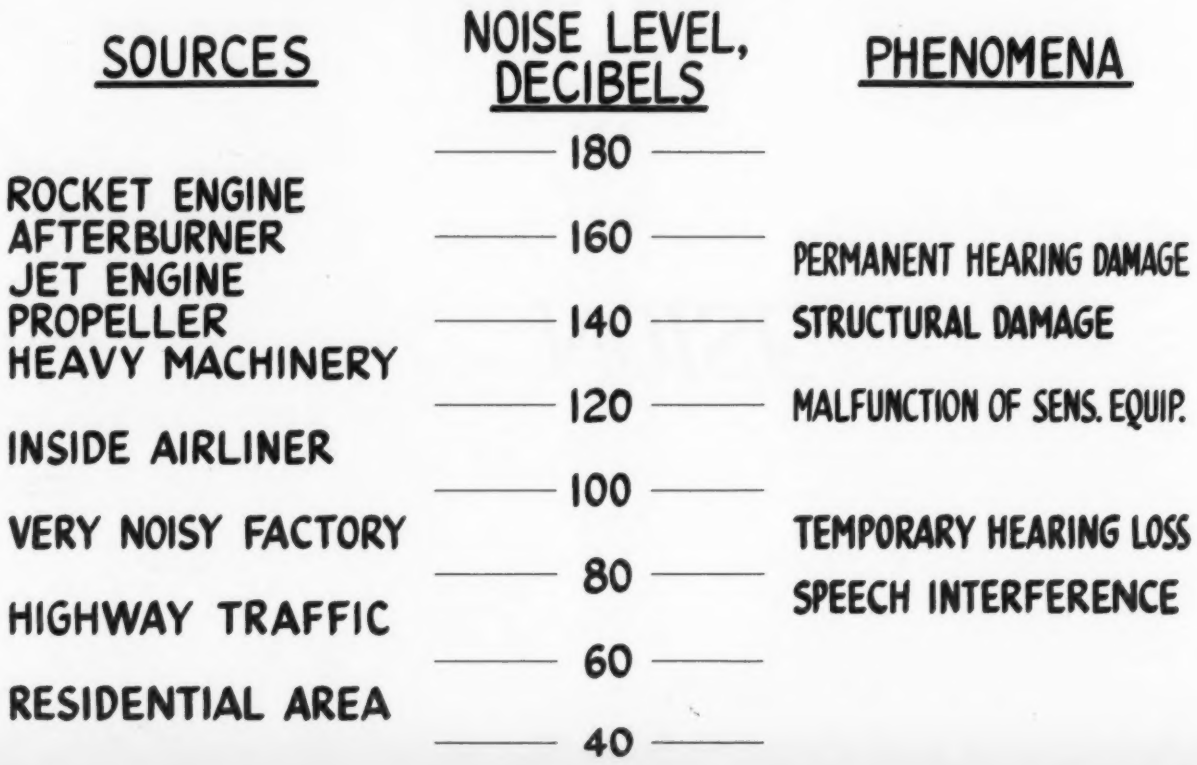
And as a case in point, the NASA is having developed a million and a half pound thrust rocket engine which will be available at some time in the future off my chart. It is estimated that this will generate about 70,000 horsepower of noise energy. This compares to 1 to 200 horsepower of noise energy from our current jet engines.

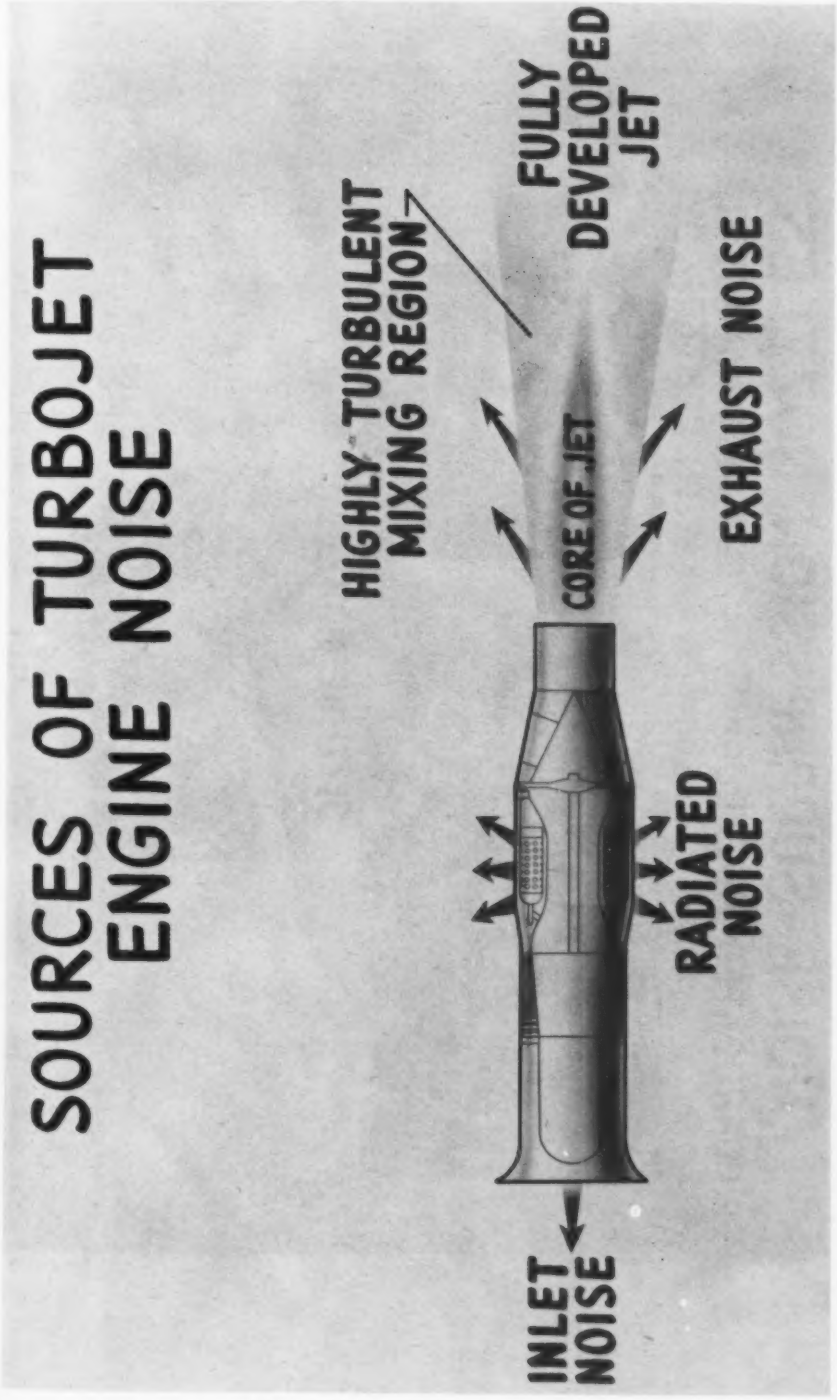
We know from experience that as more noise is generated, we have to put more effort into the noise control procedures. There is also the possibility that if noise gains are made, that they will be used up by increases in performance. So we can only conclude as we look to the future that our noise problems are continuing problems and that they will continue to require a large amount of effort for satisfactory solutions.

Thank you, sir.

NOISE

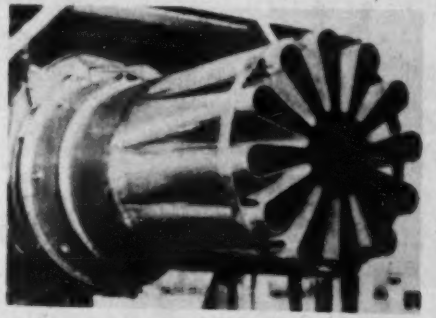
SIGNIFICANCE OF NOISE LEVELS



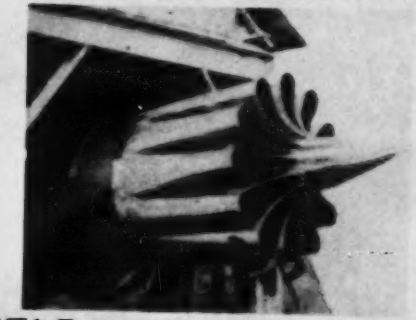

SOURCES OF TURBOJET ENGINE NOISE
HIGHLY TURBULENT MIXING REGION
FULLY DEVELOPED JET
CORE OF JET
EXHAUST NOISE
RADIATED NOISE
INLET NOISE

NOISE-SUPPRESSION NOZZLES

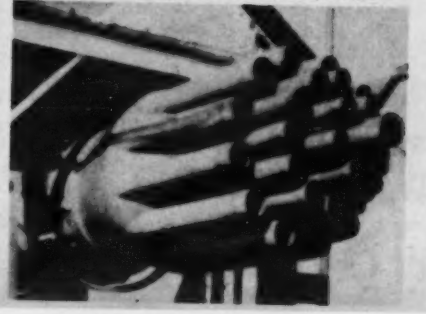
CORRUGATED NOZZLE



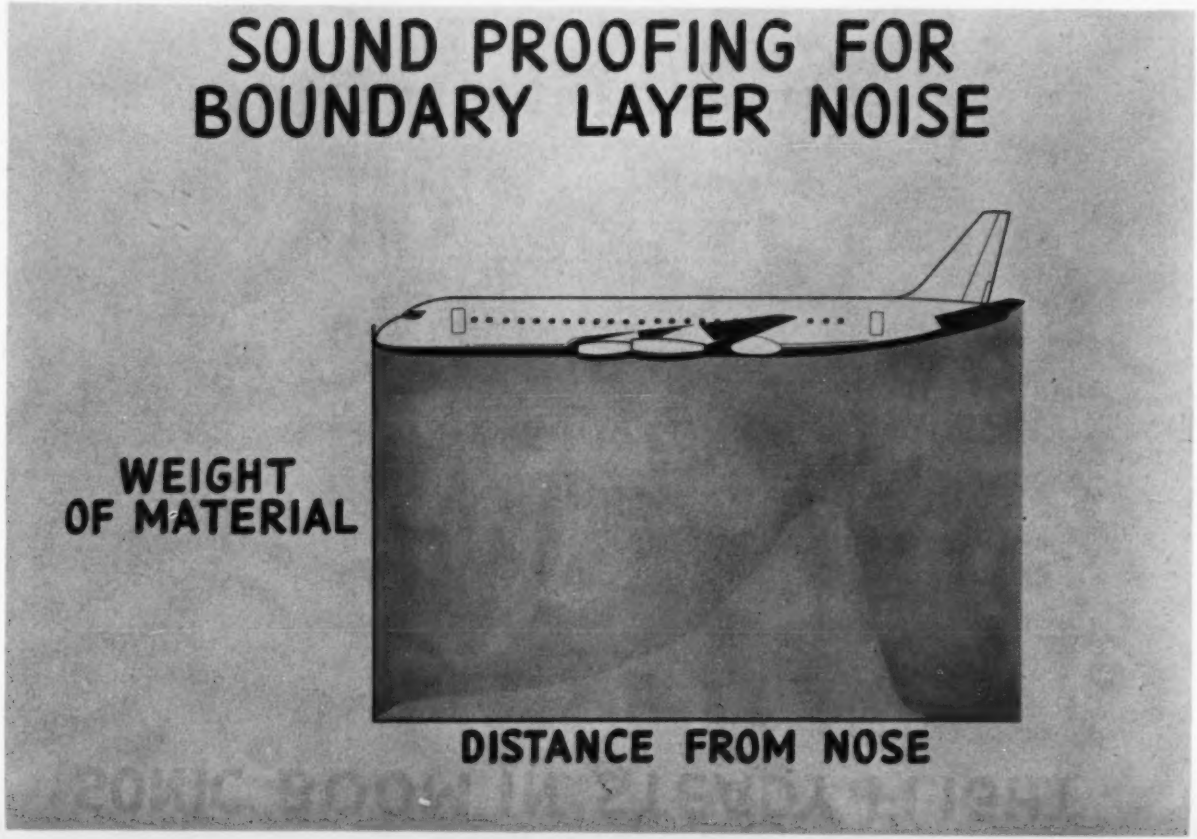
CORRUGATED NOZZLE WITH CENTERBODY

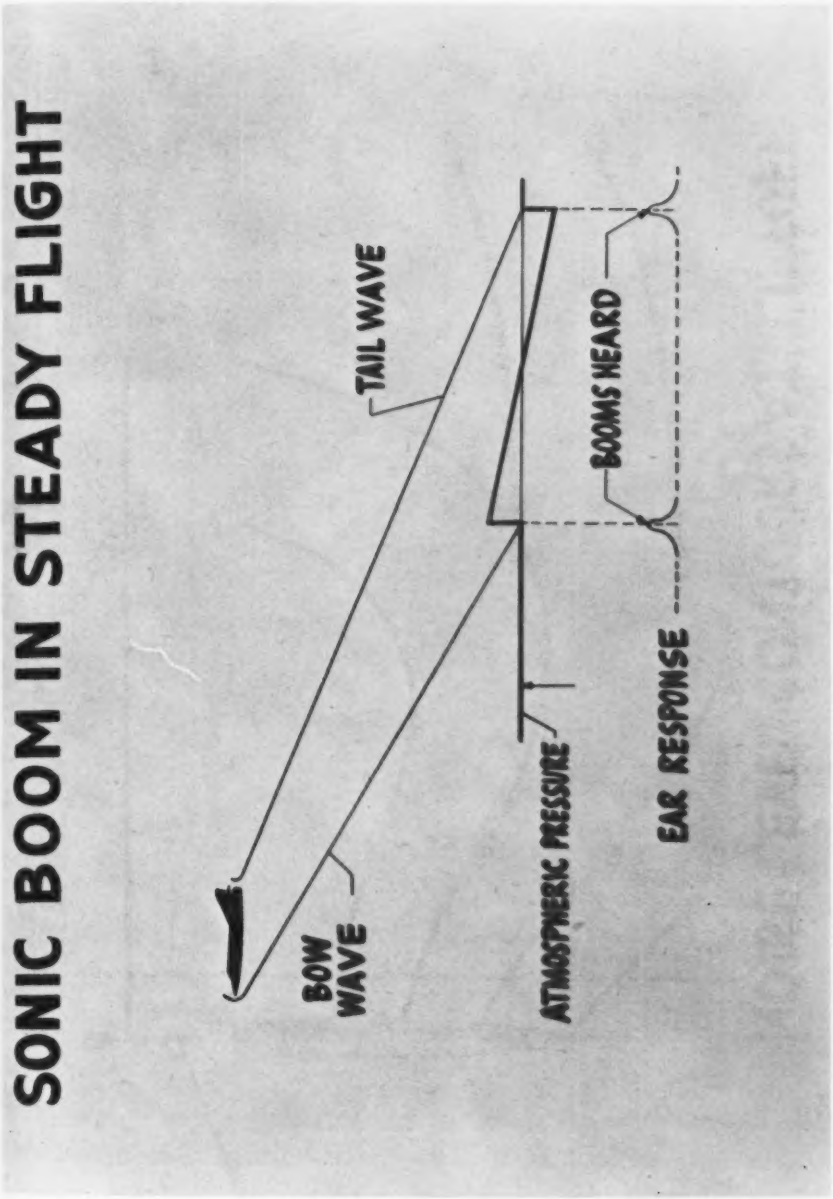


31-TUBE NOZZLE



NOISE-INDUCED STRUCTURAL DAMAGE


SOUND PROOFING FOR
BOUNDARY LAYER NOISE
WEIGHT
OF MATERIAL
DISTANCE FROM NOSE



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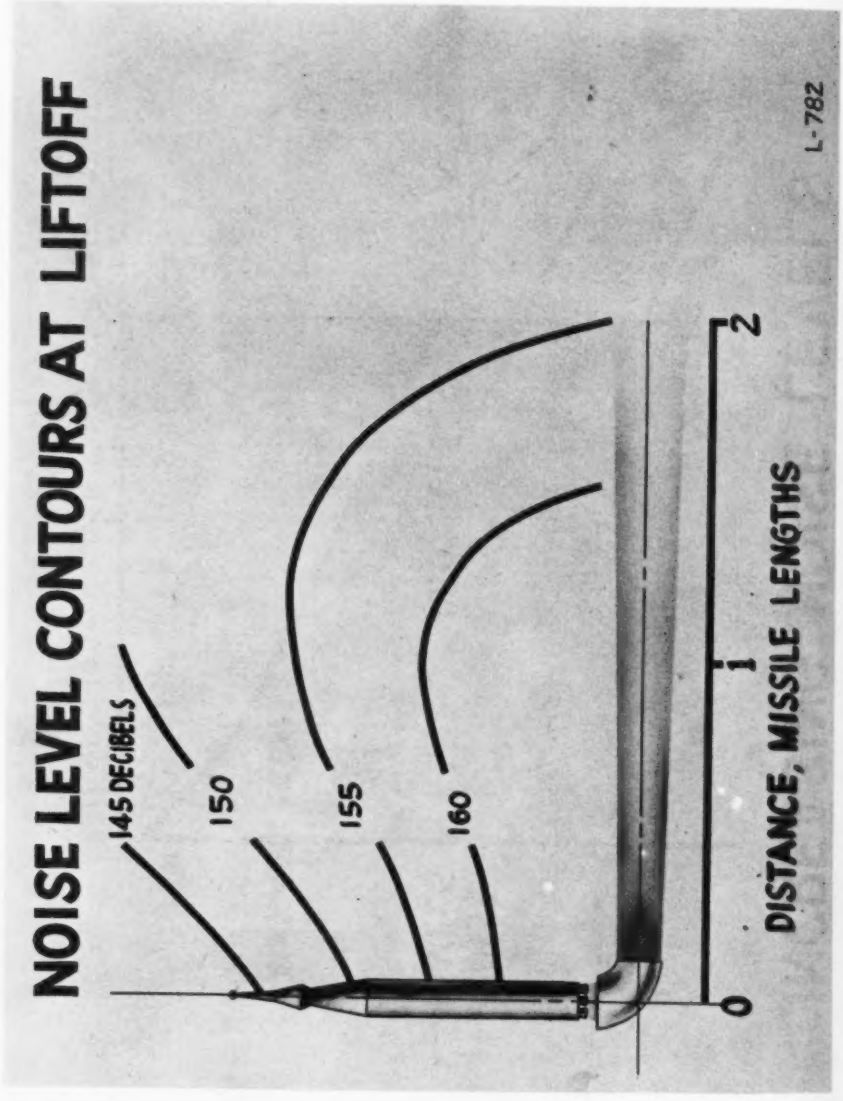
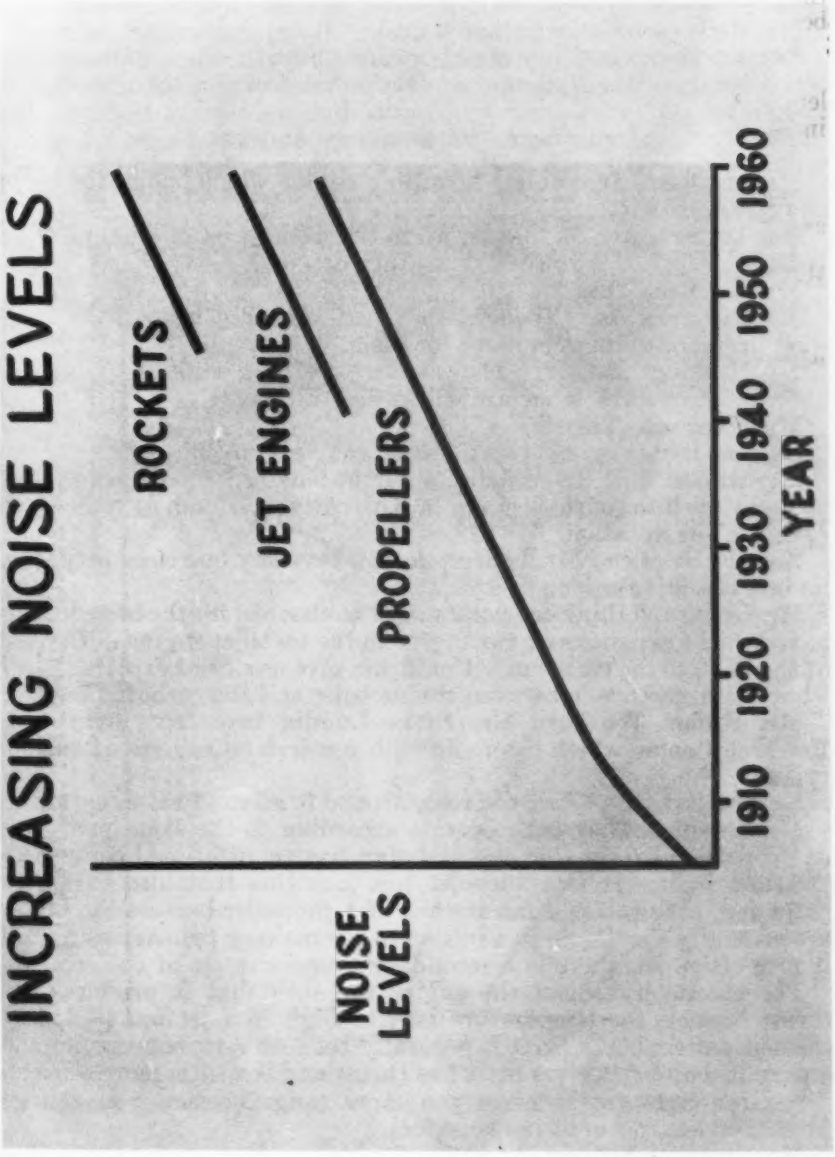

NOISE LEVEL CONTOURS AT LIFTOFF
145 DECIBELS
150
155
160
0
1
2
DISTANCE, MISSILE LENGTHS
L-782


INCREASING NOISE LEVELS
ROCKETS
JET ENGINES
PROPELLERS
NOISE LEVELS
1910 1920 1930 1940 1950 1960
YEAR

Senator STENNIS. That was a very interesting presentation, a very fine presentation. I know the Air Force won't talk about decreasing their thrust and their lifting power on these jet fighters and bombers because of what it costs them in power.

Mr. HUBBARD. Yes, sir; that is true.

Senator STENNIS. They say they can't spare it. It is quite a problem throughout the Nation, too. Just what does this term "turbojet" include?

TURBOJET AND TURBOFAN ENGINES

Mr. HUBBARD. It is an air-breathing engine which brings the air in and compresses it.

Senator STENNIS. Is that on up to the modern jet engines on these B–52 bombers? Do you call that a turbojet, too?

Mr. HUBBARD. Yes, sir.

Senator STENNIS. I thought they had advanced beyond the stage where you had a different name for them.

Mr. HUBBARD. No, sir. They are air-breathing engines.

Senator STENNIS. They are still called turbojets?

Mr. HUBBARD. Yes, sir.

Senator STENNIS. All right, thank you very much.

Mr. RHODE. Sir, this concludes our unclassified presentations, and you may wish to consider going into executive session now to hear the classified presentation.

Senator STENNIS. Mr. Lehrer, do you have any questions before we go into executive session?

Mr. LEHRER. I think one point might be clarified for the record. We have heard discussions of moving from the turbojet engine in the case of the B–52 to the turbofan. Could you give us a brief explanation of what the difference is between the turbojet and the turbofan engine?

Mr. RHODE. We have Mr. Bruce Lundin here from our Lewis Research Center which has to do with research on engines of various types.

Senator STENNIS. Will you come around briefly. I raise that point.

Mr. LUNDIN. They both operate according to the same principles of propulsion except that the turbofan has an additional component attached to it. It is a turbojet just like this that also drives an extra fan. We call it a fan instead of a propeller because the blades are generally short. So in addition to the main or primary as we call it propulsive jet, there is a secondary propulsive jet of cooler air.

The characteristics of the engine are such that it produces less thrust because the temperature isn't so high in a jet but is a more efficient powerplant. So it is generally between a turbopropeller and a pure turbojet. It gives little less thrust and is a little more efficient.

Senator STENNIS. It gives you more range because you can go further on less fuel or on the same fuel.

Mr. LUNDIN. Yes, sir.

Senator STENNIS. We have a few matters now that are classified for executive session. For the information of the press we have a short statement. This closes the open hearing covering the first phase of these scientific and technical presentations. These hearings will continue in executive session now so that the committee can consider a series of presentations that are necessarily classified, since they involve military aircraft and missile programs.

The hearings tomorrow will all be classified. The transcript of these classified hearings will be reviewed by NASA in order to delete those matters which cannot be disclosed for security reasons. The sanitized testimony will then be made an integral part of the printed record of these hearings all of which will be released publicly.

I want to especially thank all those who have appeared here as witnesses before the committee. We have been greatly impressed with your evident knowledge, enthusiasm and dedication. We regret that it has not been possible for more of the American people to share the privilege of hearing you at first hand. The record of these hearings, however, will provide a valuable and lasting contribution to our knowledge about space and related scientific programs.

I have been impressed too with the dedication and the energy of these witnesses. I am old enough to say this, I think, without offending anybody. I am impressed with the large number of young men that you have in this group here, and I am satisfied that they are the ones largely who are going to have to get on top of these problems and furnish solutions to them. I feel very encouraged from what I have seen and heard.

Mr. RHODE. Thank you, Senator Stennis.

Senator STENNIS. I thank you gentlemen for coming. Now we will go into executive session.

(Whereupon at 4:25 p.m. the committee went into executive session.)

[Executive hearings as cleared by the National Aeronautics and Space Administration—classified information deleted.]

NASA AUTHORIZATION FOR FISCAL YEAR 1960

THURSDAY, APRIL 9, 1959

U.S. SENATE,
NASA AUTHORIZATION SUBCOMMITTEE OF THE
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The subcommittee met, pursuant to call, at 4:30 p.m., in room 224, Old Senate Office Building, Senator John Stennis presiding.

Present: Senators Stennis and Dodd.

Also present: Max Lehrer, assistant staff director; Everard H. Smith, Jr., counsel; Dr. Glen P. Wilson, chief clerk; and Dr. Earl W. Lindveit, assistant chief clerk.

Senator STENNIS. All right, gentlemen. Will you proceed.

Mr. RHODE. Mr. Chairman, I had understood from some of my colleagues that you had raised some questions yesterday in connection with testimony given then with respect to matters concerning accuracy of ICBM warheads, or circular error probability. Do you wish to go into this matter at this time?

Senator STENNIS. I think you might present first what you gentlemen have in mind, and then if we have some extra time——

Mr. RHODE. All right, sir. Our next speaker is Mr. Herbert A. Wilson, Chief of the Unitary Plan Wind Tunnel Division of our Langley Research Center, who will speak to you on supersonic cruise aircraft. This refers to supersonic transport airplanes and supersonic bombers such as the B–70.

Senator STENNIS. All right, Mr. Wilson.

TESTIMONY OF HERBERT A. WILSON, CHIEF, UNITARY PLAN WIND TUNNEL DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. WILSON. The purpose of my talk is twofold. I have a twofold purpose here. First, I want to give you an idea of what some of the problems are that we work on for supersonic cruise aircraft, and secondly, to tell you how we channel the things that we find out in our research into the military aircraft designs.

To begin with, the limiting factor in supersonic cruise aircraft is the low flight efficiency that goes along with supersonic speeds. A lot of things affect the flight efficiency, such as, the energy per pound of fuel, the structural efficiency of the airplane, the propulsion efficiency—you will hear more about this later today—and the aerodynamic efficiency.

I am going to talk mainly about the aerodynamic efficiency because that is one of the most promising fields for improvement.

EFFECTS OF SPEED ON FLIGHT EFFICIENCY

To begin with, I have a chart here to show you the way the flight efficiency varies with speed.

First, the subsonic jet transports that are now flying are flying at about the peak of this curve. This chart also shows us, though, that if you get out here at around 2,000 miles per hour and get up at the top of this band of uncertainty, that the supersonic airplanes have some prospect of competing in efficiency with the subsonic airplanes now flying. They not only have the advantages of efficiency, but they have some of the other obvious advantages which go along with high-speed flight, as, for example, the ability to carry passengers.

Now, I cannot compete with Mr. Faget's 15-mile-per-gallon space craft, but here is an analogy that we have used. A 2,000-mile-per-hour transport which would carry 100 passengers would, with the utility expected, be able to carry as many passengers back and forth across the North Atlantic as the *Queen Mary* in the same time period.

This chart shows us one other thing—that the optimum airplane configuration changes with the speed. These pictures give a rough idea of what they might look like. Here are some designs that we have worked on. If time permits, I will discuss them.

The important point here is that the airplane, to fly at supersonic speeds, is going to look a lot different from our currently flying subsonic jet transports.

DRAG PROBLEMS

I am going to talk about two aerodynamic terms here. One you have already heard a lot about. This is "drag." Drag is simply the force that holds the airplane back which the thrust has to overcome for the airplane to fly through the air.

We have here the drag for a subsonic airplane compared with the drag for a hypothetical supersonic airplane such as the ones that we now have flying. First, you can see that the drag for the supersonic airplane is almost three times the drag for the subsonic airplane, and we have broken this down a little bit.

As you can see, every drag element is larger for the supersonic airplane. One deserves special mention. That is the pressure drag. That is this item we have indicated here. It is quite large. It has no counterpart at subsonic speeds. It is produced by the shock wave pattern that hangs onto the airplane much like waves hanging onto a ship and holds it back. These bars on the picture are just part of the wind tunnel window through which the picture was taken. In order for the airplane to be efficient, its surface has to be smooth to keep the friction drag low. This is just the action of the air on the surface of the airplane as it flies along. Protrusions three times the thickness of this piece of paper would be objectionable on such an airplane. Its fuselage has to be long and slender, as you can see here, and its wings have to be literally as thin as a razor blade in order for the pressure drag to be low. In order for the drag due to lift to be as low as possible, the wings have to be curved and shaped in

accord with our best available theories. All of these items have to be taken care of if the airplane is to have a low drag and thus be efficient.

STABILITY PROBLEMS

Now, obviously, drag is not our only problem. And just to introduce you to one other about which you have also heard quite a bit today in connection with the spaceships, there is the matter of stability. I will not go into detail on this chart, but there are some points which I would like to mention.

First, the stability changes with the airplane's attitude and speed. By "stability," of course, we mean that if the airplane is disturbed from its normal course, it will tend to return to its normal position without undue control action by the pilot. Also it has to be controllable so that the pilot does not have to do a continual juggling act to stay away from catastrophic flight attitudes.

Here is a wing and a tail. This is just a representation, and we have indicated a pressure field, and the angles and pressure changes in the flow field. As the tail moves it can experience very abrupt flow changes which will affect the airplane. The substance of this is that stability changes with altitude and speed and, as a consequence, the location of the tail is critical. You cannot just fix this by making the tail big, because if you do you have such a big tail on the aircraft that it penalizes the aircraft performance. One of the things we do to get away from this tail problem is to put the tail out in front of the airplane as we have done on this one, and this introduces also its own particular set of problems, which I won't go into.

The substance of this discussion is that if the airplane is going to be good, it not only has to have a low drag but it also has to be given due consideration of the stability and, of course, a lot of other factors that time does not permit us to discuss today. We have a lot of effort going on at our research centers along this direction. These models represent three different avenues of approach that we are taking and our work continues apace.

NASA INFORMATION CHANNELS WITH MILITARY SERVICES

The next subject is how we get our findings channeled into our military aircraft.

To begin with, one of our primary functions is to keep the leaders of the military services well informed of our research, and this frequently results in military system requirements being written to require performance levels that NASA research has shown to be within reach.

In addition to the military, of course, we have to keep the aeronautical industry at large up to date on our findings. Just to indicate, briefly, the manner in which this is done, I have a chart of what we call information channels. In the first place, some 700 to 800 NASA reports and memoranda on technical matters are published each year. Periodically, at appropriate intervals, we hold conferences which are attended by some 300 to 400 representatives of the military and of the aeronautical and space industry, and we review the latest research information in the fields of interest for these particular groups.

I might say that these conferences are a great help in cutting down the time that it takes to get research in the minds of our research people into the hands of the people in the military and in the industry who use it. Let me emphasize that they do make a very great use of this great bulk of material.

More direct contacts take the form of smaller meetings between the interested representatives of the military, the aircraft contractor, and the research center staff specialists in the fields of interest. They review designs; they make suggestions to avoid problem areas. Sometimes they just point out a problem area and say, "we don't know what the answer is to this, but, before this airplane amounts to anything, something has to be done here."

Another very important source of input is in specific development tests. This takes place when the aircraft company brings a model to a NASA wind tunnel or other research facility for development testing. I will go more into what we do in that case later for a specific airplane. We have prepared this chart, which is a partial list of the airplanes NASA has worked on during fiscal year 1958. The point of this chart is to show simply that there are a large number of them. Our contributions to these airplanes were not large in all cases. Some of it is rather small. But in other cases it is a major contribution.

NASA CONTRIBUTIONS TO THE B–70

As an example of one of the major cases we have picked the B–70 bomber, and I will talk about that in more detail. The detectable NASA contributions to the B–70 aircraft starts with a wind tunnel model in 1956. Now the results we got with this model and with a large number of other configurations we tested——

Senator STENNIS. That is a model of what, Mr. Wilson?

Mr. WILSON. This is a wind tunnel model. This is an actual photograph of a model that was tested back in 1956. It is from models such as this that we developed the curve to predict the flight efficiency which I showed you earlier.

Senator STENNIS. Yes. But it did not take form and become a fighter or something of that kind?

Mr. WILSON. No. This is a research model that originated within the NASA research centers. Does this answer your question, sir?

Senator STENNIS. Yes. I see. Go ahead.

Mr. WILSON. This is the way we operate. A lot of the work we do such as this originates in the minds of the researchers who are working in this area.

At any rate, the point here is that we tested a number of models and we developed curves of flight efficiency which indicated that supersonic airplanes look promising. As a consequence, as I mentioned earlier, the military wrote a systems requirement to stimulate some interest in the design of supersonic cruise bombers with an intercontinental range capability.

In late 1957, two contractors produced acceptable designs and were given competitive design contracts. During this phase the NASA worked equally with both contractors, but I will talk only about the North American one, which was the one that finally got the construction contract, as you no doubt know.

The North American B–70, just to refresh you, is here, and you will note the similarity of this to the research model. When it became quite evident that the Air Force wanted to go ahead with this program, the research centers instituted a "high urgency" program to look into all of the phases—aerodynamic and other phases—that would support this effort, and these models that you see here are partially an outgrowth of this program.

In addition, at the Ames Research Center, some wind tunnel models of the particular design as laid down by North American were tested and developed through a large number of configuration changes to see what could be done to make this airplane better, and this work continues on now even up to the present, and somewhat in the future, to help to make this airplane the best obtainable. Likewise, the work we are doing with models like this, which is also contributory, is continuing at the Langley Research Center.

CONTINUING RESEARCH ON AERODYNAMIC EFFICIENCY

Now as to the level of accomplishment, we have a final curve here. This factor here is aerodynamic efficiency, and the higher you are the better it is. This is plotted against Mach number, but to get back to speed, which is a little bit easier to understand. Mach No. 3 is just about 2,000 miles an hour, the speed that I talked about earlier.

Included on this chart is a curve for the B–58 airplane, which as of the day it was built, or as of the day its design was frozen, incorporated the best and latest aeronautical knowledge we had.

Here is a curve for one of the preliminary versions of the B–70, and I emphasize "preliminary." The difference between these curves is an index of the aeronautical progress of the intervening time. These research models that you see here, the white ones, produce curves along in this range, and the latest versions of the B–70 are also getting in about this range.

Of course, this research is a continuing thing, and it is a bit dangerous to make predictions. Nevertheless within about 5 years we expect to be able to push the level of this curve to about this range here.

To give you an idea of what one of our directions is, we have this airplane model here, and, as you can see, when you look at it from the front it does not present much to see. All of the elements that we could line up behind each other to keep the pressure drag low are lined up. The wing is blended into the fuselage. You will notice the fuselage was made wide and flat, which gives it a high lifting efficiency. All of these models are models of complete airplanes, since they have the proper volume for cruise, armaments, crews, stores, and this sort of thing. They have the instrumentation, the tail surface necessary for stability, and, in other words, they are complete.

Just by way of conclusion——

Senator STENNIS. I hate for you to conclude. This is very interesting.

Mr. WILSON. There is one more point I want to make. We have told you what some of the problems are, and I will be glad to discuss these as long as you wish. We have told you how we translate these findings

into our military aircraft, and there is one other thing which is a worthwhile byproduct. This is the fact that development work on specific aircraft like the B–70 is very stimulating to our research activity. It adds a lot of realism to the thinking of the people who are working on the different problems. Moreover, we feel that it gives us a lot of insurance, when we keep our military planners up to date, to make sure that our aircraft are the best in the world.

Thank you.

AERODYNAMIC PROBLEMS OF SUPERSONIC CRUISE AIRCRAFT

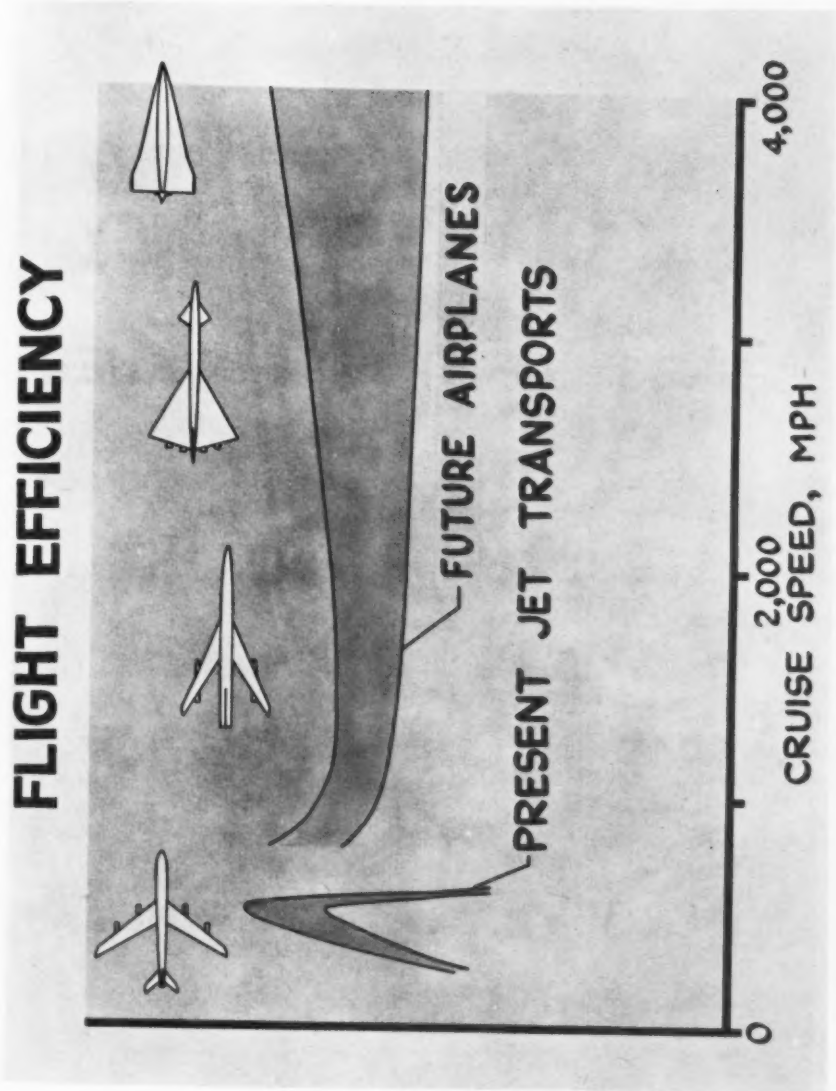
FACTORS AFFECTING FLIGHT EFFICIENCY

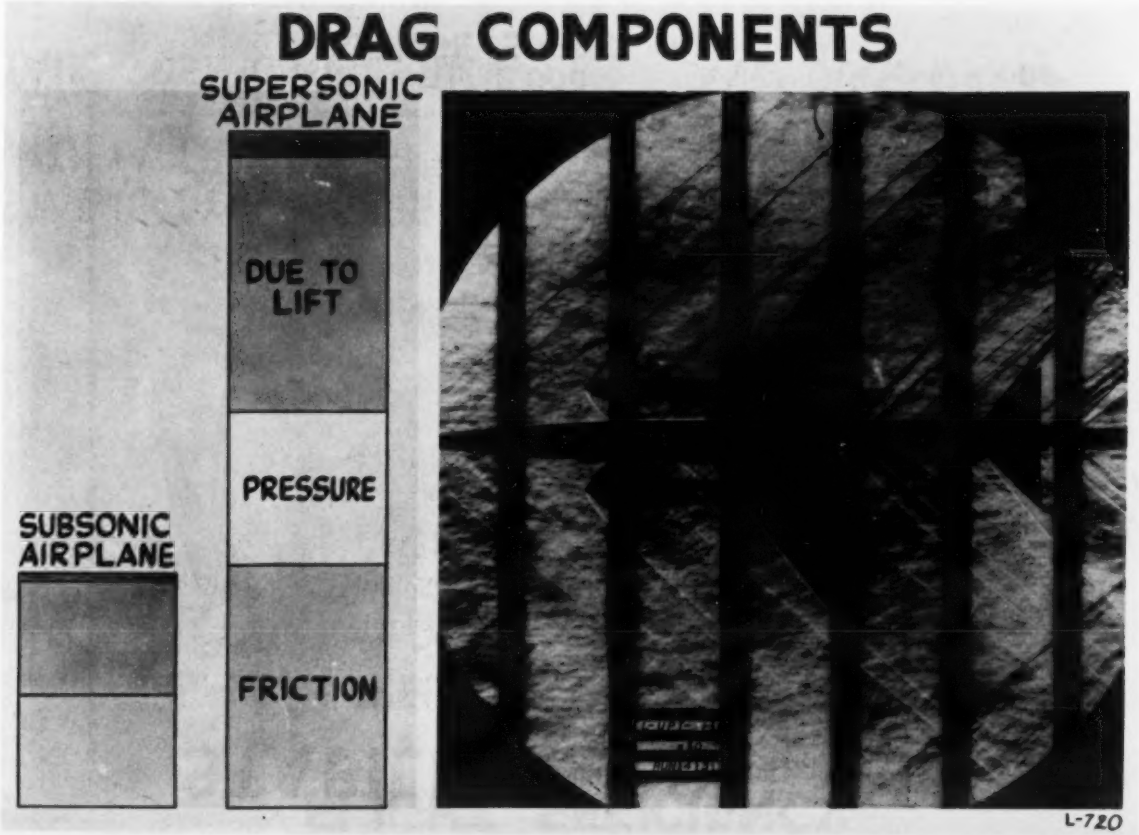
ENERGY PER POUND OF FUEL

STRUCTURAL WEIGHT

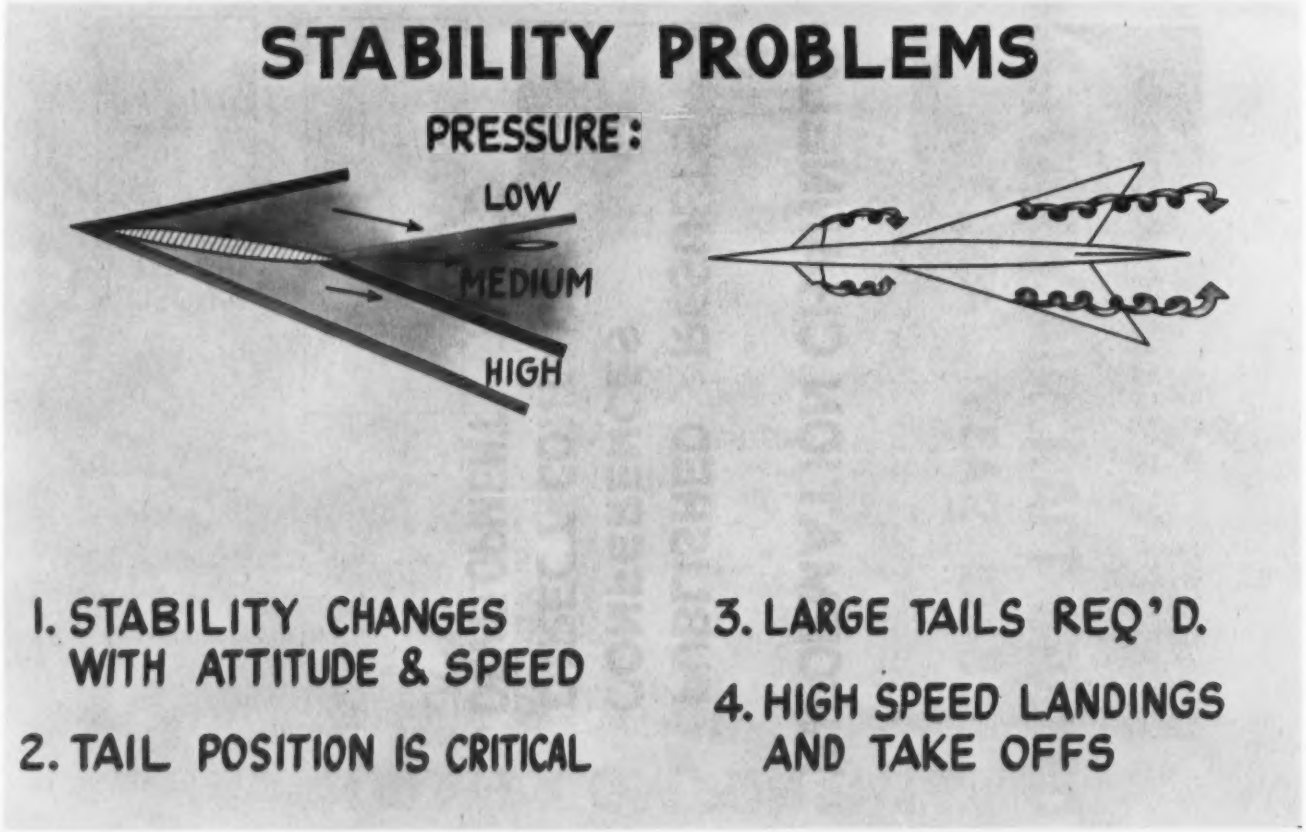
PROPULSION EFFICIENCY

AERODYNAMIC EFFICIENCY


FLIGHT EFFICIENCY
FUTURE AIRPLANES
PRESENT JET TRANSPORTS
0
2,000
4,000
CRUISE SPEED, MPH


DRAG COMPONENTS
SUPERSONIC AIRPLANE
DUE TO LIFT
PRESSURE
FRICTION
SUBSONIC AIRPLANE
L-720

L-720

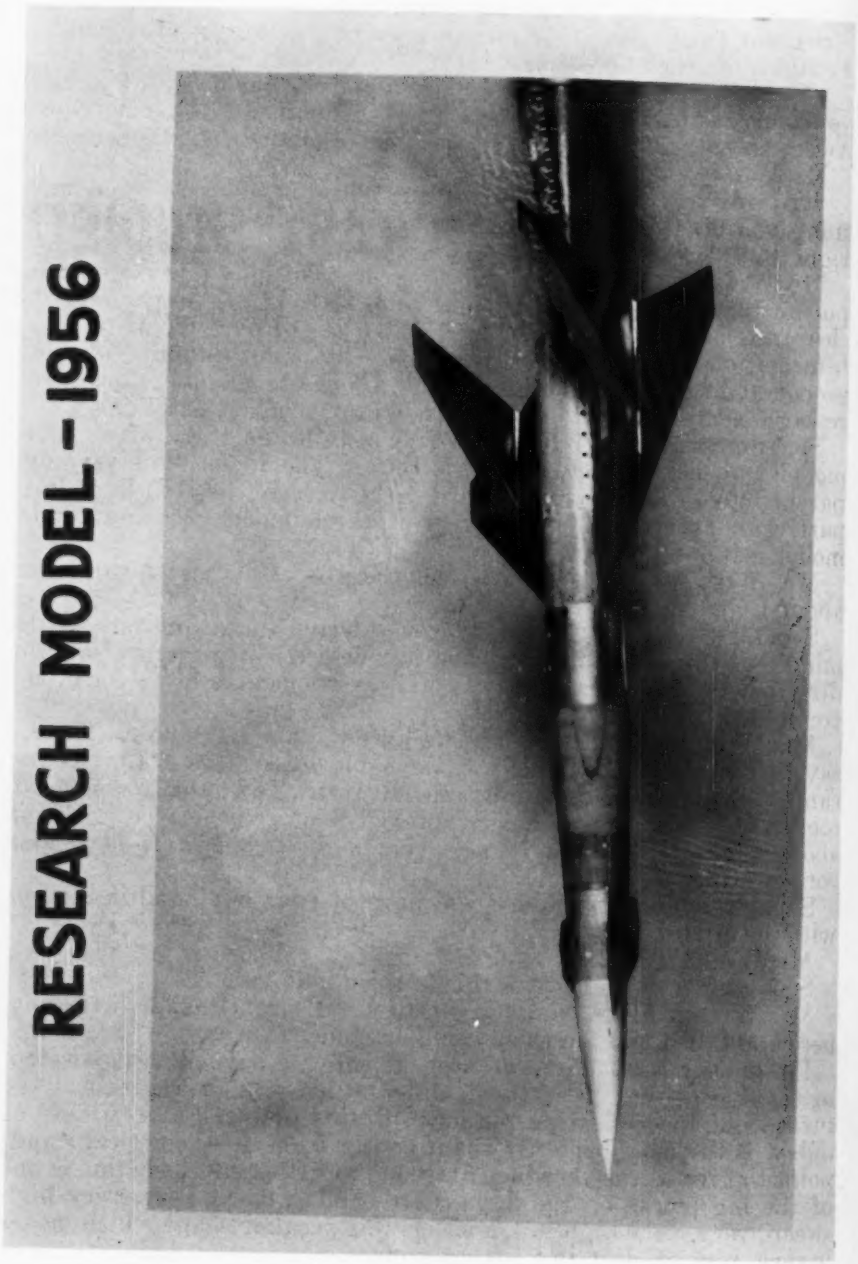

STABILITY PROBLEMS
PRESSURE:
LOW
MEDIUM
HIGH
1. STABILITY CHANGES WITH ATTITUDE & SPEED
2. TAIL POSITION IS CRITICAL
3. LARGE TAILS REQ'D.
4. HIGH SPEED LANDINGS AND TAKE OFFS

INFORMATION CHANNELS

PUBLISHED RESULTS
CONFERENCES
DIRECT CONTACTS
DEVELOPMENT TESTS

MILITARY AIRCRAFT STUDIED
FISCAL YEAR 1958

F-103
F-104
F-105
F-106
F-107
F-108
F-4H-1
F8U-1
F8U-3
A3J
D-188A
P6M
B-58
B-70
M-329-C-1


RESEARCH MODEL - 1956

Senator STENNIS. Very fine.

Senator Dodd, do you have any questions?

Senator DODD. No. It is very interesting. I am like you, Senator, I could listen for a long time.

Senator STENNIS. May I ask one thing. As I understand it, now, you make available to all these private companies, such as North American or any other manufacturer, the benefit of your experiments.

Mr. WILSON. Yes, sir.

Senator STENNIS. And it is just like in cotton research, where anything you do will benefit any cottongrower or textile man. Is that right?

Mr. WILSON. This is absolutely correct. The only proviso I would put on that, on work such as this he must have the proper security clearance, but this is all. In fact, we go out of our way, if we have information we think a particular company ought to know, why, we go out and say, "You ought to come to one of our laboratories," or research centers as they call them now, "and look at this."

Senator STENNIS. You had a picture a while ago of the wind tunnel model and later a picture of this B–70. The B–70—it is very apparent to one who is looking, but for the record—the B–70 is at least partly an outgrowth of this very research model or wind tunnel model, is it not?

Mr. WILSON. Yes, sir. We feel there is absolutely no question about that.

Senator STENNIS. This model you referred to sitting here in the middle of the table that you have just described, that represents the direction of passenger planes as well as bombers, and so forth, the trend?

Mr. WILSON. This is the best we have to offer right now. We can say that this is good, though we have not tested it yet. But, as you can see, it represents a considerable advance. This other one is good, too, by the way, and we have improved this one somewhat. This is about a great-grandson, I guess you might say, of this particular configuration.

Senator STENNIS. The one you have in your left hand is the one with the tail in front.

Mr. WILSON. That is right.

Senator STENNIS. What is this in the middle?

Mr. WILSON. This one is a variation. I might take a little time here and talk about these two configurations.

Let me say this: We want to make sure we have all bets covered, so these are three distinctively different avenues of approach. We turned our theoretical people loose on this problem, and this, as of today, is the most perfectly shaped wing from the theoretical standpoint to give us the very best drag due to lift—remember, this is one of the big blocks on the drag chart—and it has a very, very high sweep, very, very high tail, and has this peculiar shape which makes it very, very efficient as a lifting surface.

Senator STENNIS. Is that model still being considered for further development?

Mr. WILSON. Oh, yes, sir. We have one or two models of additional versions of this which are actually now under construction for wind tunnel tests. This particular one here has two things to recom-

mend it. One is this. I guess I will have to define "stability." This one has a very small change in stability from your landing approach and takeoff, very small change in stability in that case and in the supersonic cruise case.

Moreover, this one looks pretty good if we can reduce some of the temperature limitations on the engine, structure, et cetera., and push our man-carrying, air-breathing aircraft to higher speeds, where we are working very intensively now. This one looks like it may have some promise.

Mr. RHODE. Mr. Chairman, I would like to address myself to your question about the applicability of these configurations to the transport problem. Past history of aeronautical development has always followed a certain pattern, which is that military developments take place first, and then after a certain time has elapsed and it is no longer necessary to retain the classification of the configuration, it is open to the civilian aircraft builders to build.

So I think it might be fair to state that this model in the middle of the table, which is currently classified, perhaps represents what the transport airplane of the future might look like.

Mr. WILSON. I might supplement that, if I may, and say that we have talked with some three or four aircraft companies already who are beginning to study what they can do with transport designs such as this, and they are following this development quite closely.

Senator STENNIS. All right, thank you very much, Mr. Wilson. Suppose we move along now and complete our hearing of all the witnesses, and then if we want to come back again, we can. Who do you have next, please?

Mr. RHODE. We have Mr. Bruce T. Lundin, sir, Assistant Director of our Lewis Research Center. He will speak on chemical air-breathing propulsion systems.

Senator STENNIS. All right, Mr. Lundin, come right around. Mr. Wilson, you are from Langley, are you not?

Mr. WILSON. That is right. Incidentally, I am from Mississippi originally.

Senator STENNIS. I knew there was some strong reason why you were making such a good presentation. We will have to talk some more. I suspect we have some mutual friends.

All right, Mr. Lundin.

TESTIMONY OF BRUCE T. LUNDIN, ASSISTANT DIRECTOR, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO

Mr. LUNDIN. I am here today to talk about the engines that are going to power these airplanes into the higher speed region.

The achievement of satisfactory engines for supersonic airplanes was, as you know, the subject of an intensive research-development effort for a little over a decade, carried out by the military services, by private industry, and by the different research centers of the NASA.

SUPERSONIC PROPULSION CAPABILITY

Our present capabilities today for supersonic propulsion which has come about from the combined and cooperative effort of all of these

organizations is shown in my first chart. We have plotted this capability in terms of flight speed and altitude.

In addition to the operating limits of particular kinds of engines, two other rather general limits are shown here, one that is called an aerodynamic limit and the other is an engine stress limit.

As we fly at higher and higher speeds at a given altitude, the air that strikes and enters the engine has a higher and higher kinetic energy. The ram effect of this energy of motion tends to raise the engine stresses, and it is necessary to use progressively stronger and heavier engines.

While this limit will, of course, vary somewhat, therefore, with a particular kind of engine or application, in general the high-speed, low-altitude conditions below this stress limit line must be avoided if we are to obtain efficient, lightweight aircraft powerplants.

On the other hand, if we attempt to increase the altitude at a given speed, the air becomes less dense and both the thrust produced by the engine and the lift development by the airplane decrease.

These effects conspire in such a manner that effective sustained flight by air-breathing engines is not possible in the high altitude region above this line. So these two lines thus establish this so-called corridor of possible continuous flight.

Within these general limits the operating envelope of particular engines will be further defined by their particular design arrangements, and I have shown them here for our present turboprop, turbojet, and ramjet engines.

The turboprop, such as used in our present Viscount civil transport, is limited to subsonic speeds of about 400 miles an hour. The turbojet extends this spectrum into the supersonic speed region, with some engines in production development being capable of efficient flight at about 2,000 miles per hour at altitudes of around 70,000 feet.

The ramjet engine, such as used in our current Bomarc or Talos missiles, is now undergoing flight development testings at speeds of about 2,000 miles an hour, and the technology necessary to build engines for about 2,500 miles an hour and 100,000 feet in altitude is available. Well, these, then, are our general capabilities at the present time.

THE TURBOJET

To inquire further into the nature of these limits, and particularly what must be done to extend them, I would like to refer to my next chart. In this chart I have shown two engines, one a future turbojet engine that might be used for a speed of about 2,700 miles an hour, and a future ramjet engine that has been designed for a speed of 5,000 miles an hour.

In any turbojet engine, four processes are necessary to develop a propulsive thrust. First, the air must be inducted into the engine in an appropriate inlet system. This air must then be successively increased in pressure, which is the function of the inlet and the compressor, and heated to a high temperature in the combustion chambers.

Part of the energy of these hot gases is used by a turbine to drive the compressor. So we then have in the rear portion or the tailpipe of the engine a high-pressure, high-temperature gas. This relatively

slow-moving but high-temperature gas is then accelerated to a high velocity and ejected by an exhaust nozzle, so it is the reaction to this increase in velocity of the air going through the engine or, in other words, the pushing of the engine on the gases, that makes the propulsive thrust.

THE RAMJET

The ramjet operates in a very similar manner to the turbojet, except that in this case the entire pressure of the air prior to heat addition is accomplished in the inlet by virtue of the ram effect that I mentioned earlier. No compressor and turbine assembly is therefore required, and considerable simplification results.

The absence of this compressor-turbine, however, means, of course, that this engine cannot produce thrust at takeoff and low-speed conditions, and so it has to be boosted to operating speeds by other devices, usually rockets.

PROBLEM AREAS

Many difficult problems exist if we are to obtain a 2,700-mile-per-hour turbojet engine. It can be stated that the research knowledge necessary for this development currently exists. The development of this technology has been for the most part a struggle with the high-temperature environment of high-speed flight.

For example, at a speed of 2,700 miles an hour, the inlet air temperature is about 1,200° F., and increases very rapidly with further increases in flight speed. These high temperatures introduce two basic difficulties.

TEMPERATURE

First, the obvious one of the temperature limits of the materials that are used; and, secondly, the necessary compromises in designs that are necessary to get an engine which will work well at both an inlet temperature of 1,200° and at the very low temperatures of low-speed flight.

Considering the material temperature limit, it becomes necessary at speeds in excess of 2,700 miles an hour to cool the compressor and the turbine by circulating fuel or some other coolant through all of their parts.

This, of course, can be done. The only place to which this heat may be rejected is into the fuel itself. Now, the amount of heat that may be rejected to the fuel is, of course, limited, and we reach a limit of practical fuels for jet engines at about 3,000 miles per hour.

Higher speeds are certainly more likely to be obtained with the ramjet type of engine. Here again, of course the dominant problem in a high-speed ramjet engine is that of enabling the engine to endure the very high temperature of high-speed flight. Some idea of what these temperatures are is shown in this chart, where the temperature is plotted for different flight speeds.

The upper blue curve is the temperature that the walls of the combustion chamber are exposed to, and this green curve the temperature of the walls of the inlet of the engine.

Also shown on here are the temperature limits of some available and foreseeable materials. With present steels and high-temperature alloys, they become practicable for only the inlet diffuser for speeds in the region of about 3,000 miles per hour.

A ceramic-coated steel or a coated molybdenum will permit increases in speed of perhaps a thousand miles an hour. At 5,000 miles an hour, however, these temperatures range from about 5,000° in the inlet diffuser to 6,000° in the combustion chamber wall, so it is evident, therefore, that speeds in this range will require very special cooling of all parts of the engine.

So again the problem of speed limits resolves itself into this heat-absorbing capability of the fuel, and some of these limits are in my next chart, again in terms of altitude and flight speed, with these two blue curves representing a corridor of possible continuous flight.

FUELS

With conventional jet fuels and present steel construction, speed capabilities of about 3,500 miles an hour are indicated. Pertinent to this limit with this hydrocarbon fuel is the fact that these fuels may only be heated to about 600° or 700° F. before they crack and form undesirable gums in the engine fuel system.

A cleaner fuel which can be heated up to higher temperatures and thus do more cooling is methane. If this fuel, normally a gas, is refrigerated and liquefied and used for a high temperature alloy engine, a speed of a little over 4,000 miles an hour should be possible.

Higher speeds require the use of liquid hydrogen fuel. Liquid hydrogen is outstanding in regard to both cooling capacity and energy content. Compared to conventional jet fuels, it can do about 10 times as much cooling, and it has an energy content nearly three times as great. It also possesses, however, some outstanding logistics and handling and design difficulties.

Its low density of about 4½ pounds per cubic foot implies very large tanks and aircraft structure, and associated weight penalties; and we have to handle it and maintain it at temperatures very close to absolute zero, or about minus 425° below zero on the Fahrenheit scale.

For these reasons it has not been considered a suitable fuel for military applications requiring short notice operational readiness. It can, however, permit the jet engine to fly at high speeds. Although calculations in this area cannot be precise at the present time, a maximum speed of perhaps 6,000 miles an hour is possible.

In addition to these speed and altitude limits, a third flight parameter of considerable importance is, of course, that of flight range, how far you can fly. Factors pertinent to flight range from a propulsion standpoint are the engine efficiency and the heating value of the fuel.

At the present time, engine efficiencies are running at a pretty high level. The efficiency of all of the components of the engine are in the 90 percent range. Further research in this area is rewarded with diminishing returns.

HIGH ENERGY FUELS

Our main current interest in increasing the range of our future aircraft is centered in the application of high energy fuels, or, more specifically, in the use of boron hydride fuels which have an energy content that is about 35 percent greater than that of conventional fuels.

Some idea of what the use of a boron hydride fuel would do in the way of increased range is shown in this chart. With conventional fuels, a range of 7,000 or 8,000 miles is indicated, depending somewhat on the flight speed. With boron hydride fuel, a flight range of over 10,000 miles is possible at speeds of about 2,000 miles an hour.

Now, the combustion of this fuel in air produces, of course, boric oxide, and boric oxide is a solid at room temperatures, and a very heavy, viscous liquid at engine operating temperatures.

In operating engines and turbines with this sticky mass of combustion products being continuously formed, it has, of course, given us many difficulties. Some of these difficulties and our present solutions are shown in the pictures on my last chart.

The pictures over here in the left-hand portion of the chart show what happened when we attempted to burn this fuel in standard combustion chambers and with conventional turbine blades. Very heavy deposits of oxides were formed on these parts of the engine that seriously depreciated engine performance, of course, and rendered the engine inoperable in a few minutes.

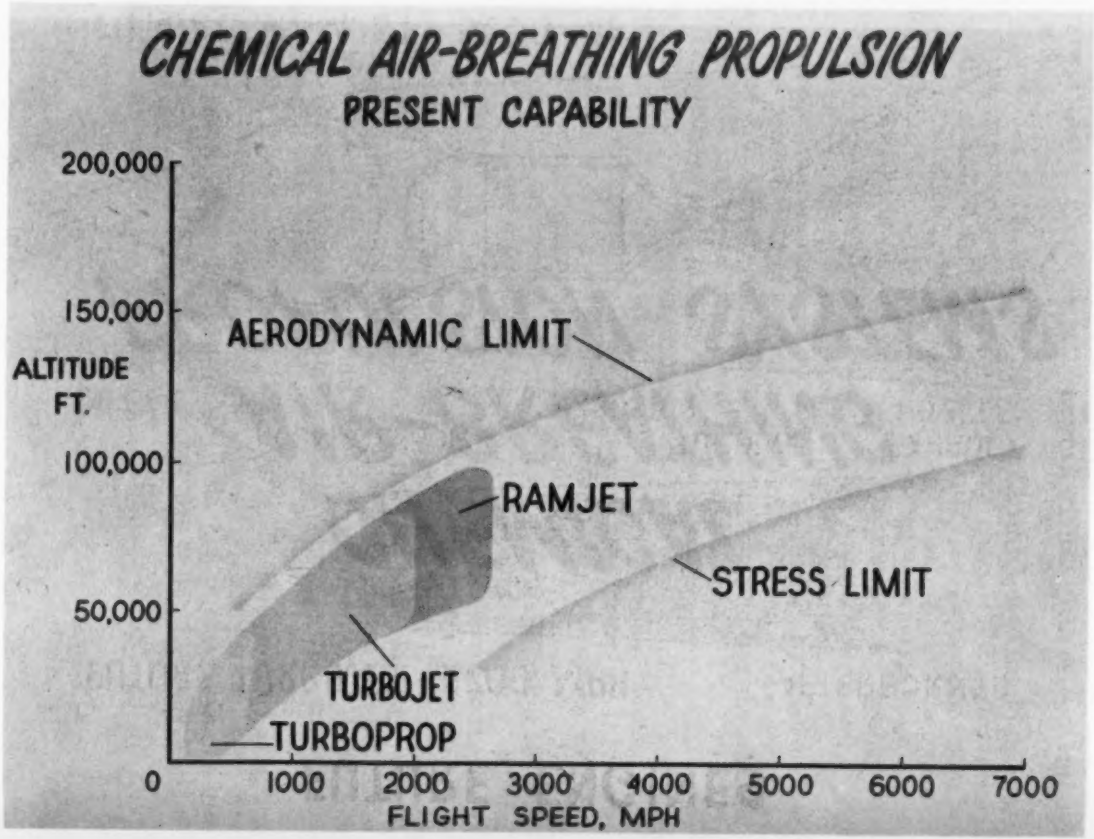
New principles of fuel injection, new ways of designing the combustion chamber, and new kinds of blades were obviously required here. By applying the concepts learned in basic research to the design of these components, the results shown by these two photographs in the right-hand portion of the chart have been recently obtained.

The special combustor has been operated at high efficiency without excessive or harmful deposits, and the special shaped turbine blades are also in a fairly clean condition, and performance measurements on these turbine blades indicate that satisfactory performance should be obtained in a complete engine.

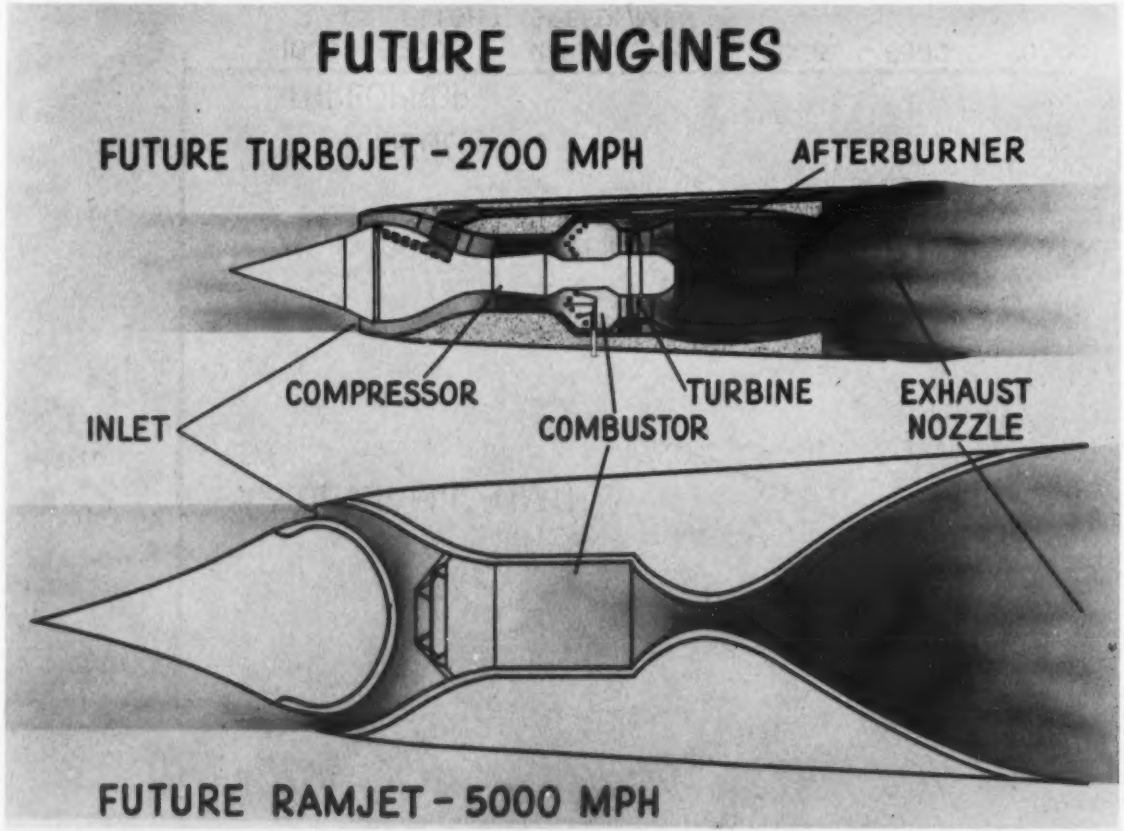
So our current research in this area is directed toward applying these concepts to a complete engine, investigating performance over a wide range of conditions. While I do not intend to imply here that the application of this fuel to engines is development ready at the present time, our research here during the past year or two has been quite encouraging, and is being energetically pursued.

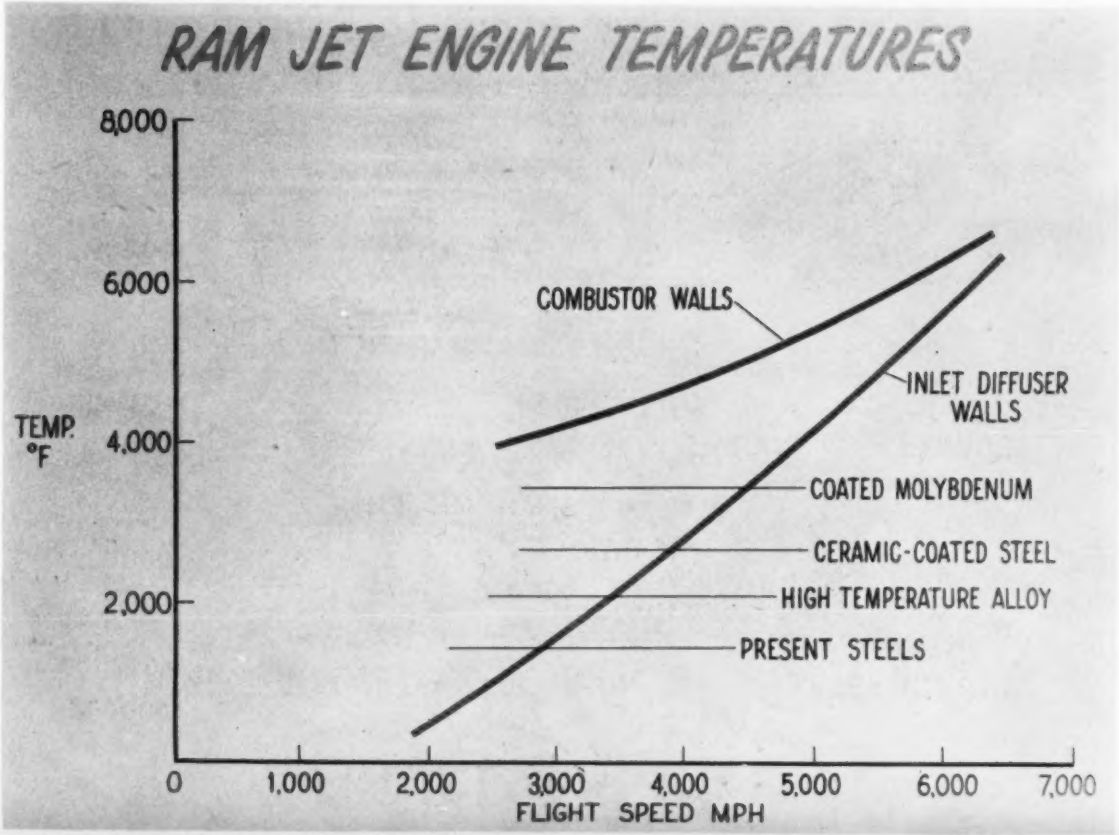
Thank you.

CHEMICAL AIR-BREATHING PROPULSION SYSTEMS

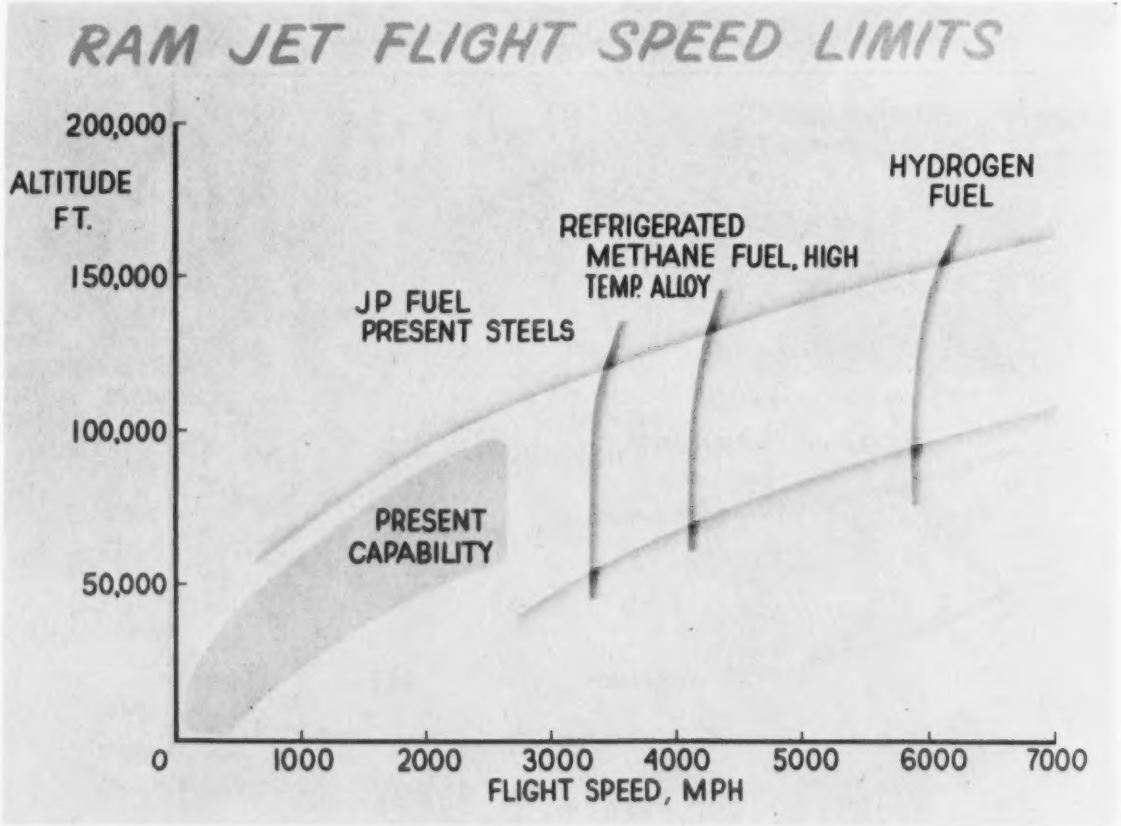

CHEMICAL AIR-BREATHING PROPULSION
PRESENT CAPABILITY
200,000
150,000
ALTITUDE FT.
100,000
50,000
0
AERODYNAMIC LIMIT
RAMJET
STRESS LIMIT
TURBOJET
TURBOPROP
1000
2000
3000
4000
5000
6000
7000
FLIGHT SPEED, MPH

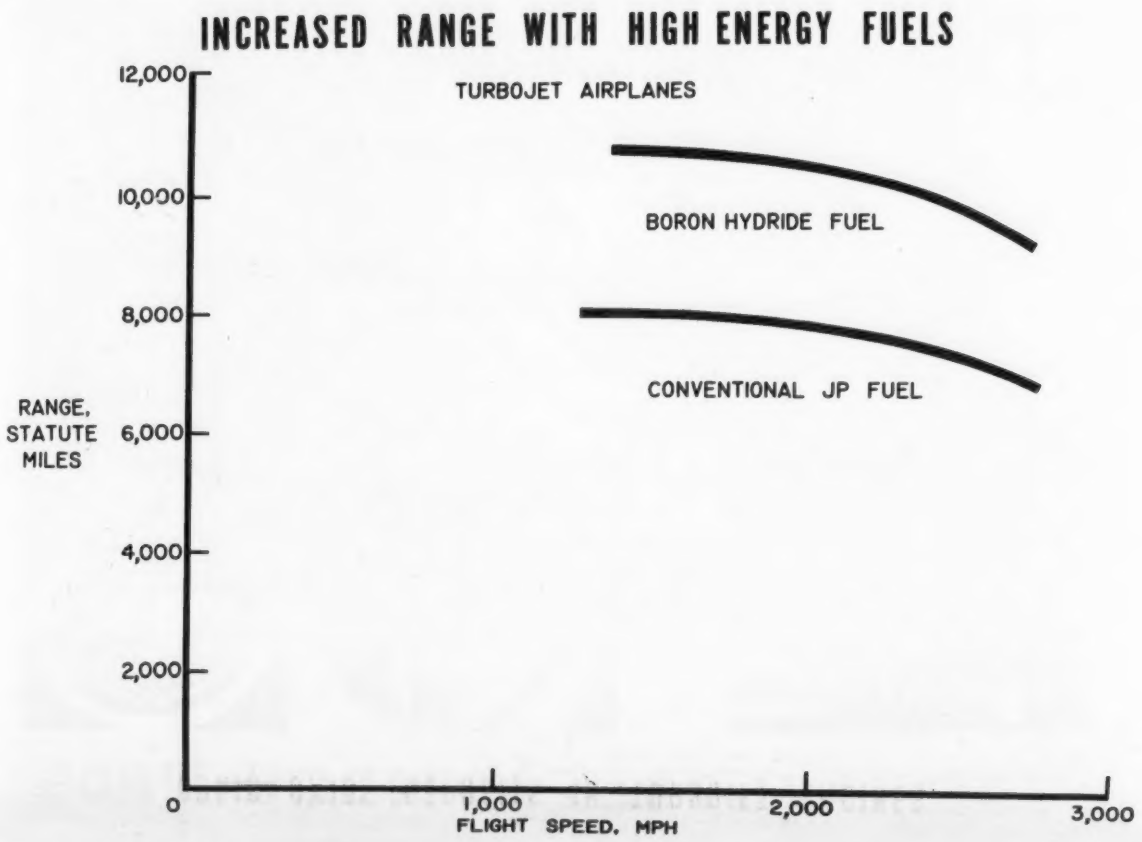
0
1000
2000
3000
4000
5000
6000
7000
FLIGHT SPEED, MPH


FUTURE ENGINES
FUTURE TURBOJET - 2700 MPH
AFTERBURNER
COMPRESSOR
TURBINE
EXHAUST NOZZLE
INLET
COMBUSTOR
FUTURE RAMJET - 5000 MPH

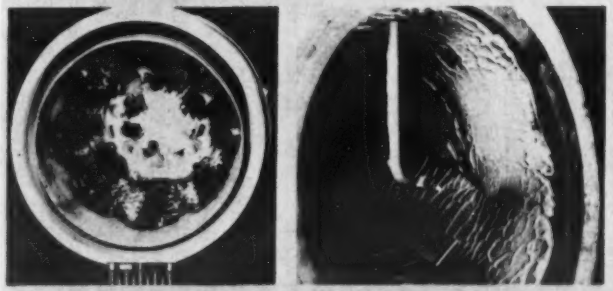

RAM JET ENGINE TEMPERATURES
8,000
6,000
4,000
2,000
TEMP. °F
COMBUSTOR WALLS
INLET DIFFUSER WALLS
COATED MOLYBDENUM
CERAMIC-COATED STEEL
HIGH TEMPERATURE ALLOY
PRESENT STEELS
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
FLIGHT SPEED MPH

0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
FLIGHT SPEED MPH

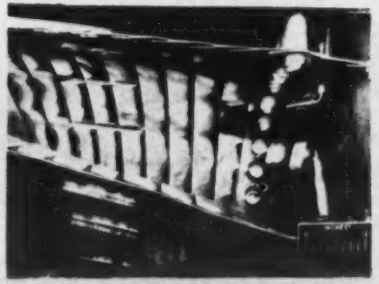

RAM JET FLIGHT SPEED LIMITS
200,000
ALTITUDE
FT.
150,000
100,000
50,000
0
1000
2000
3000
4000
5000
6000
7000
FLIGHT SPEED, MPH
HYDROGEN
FUEL
REFRIGERATED
METHANE FUEL, HIGH
TEMP. ALLOY
JP FUEL
PRESENT STEELS
PRESENT
CAPABILITY


INCREASED RANGE WITH HIGH ENERGY FUELS
TURBOJET AIRPLANES
BORON HYDRIDE FUEL
CONVENTIONAL JP FUEL
RANGE, STATUTE MILES
12,000
10,000
8,000
6,000
4,000
2,000
0
1,000
2,000
3,000
FLIGHT SPEED, MPH

BORIC OXIDE DEPOSITS IN TURBOJET ENGINES

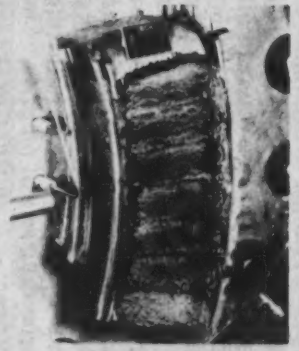


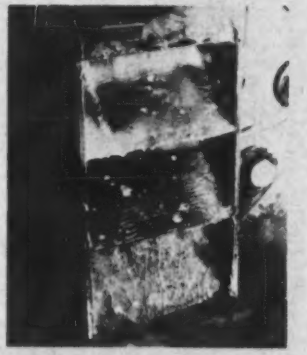
STANDARD COMBUSTOR



RESEARCH COMBUSTOR

STANDARD TURBINE BLADES





RESEARCH TURBINE BLADES

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Senator STENNIS. Thank you very much, Mr. Ludin. We may have questions for you in a minute.

Mr. RHODE. Yes, sir. Our last presentation for today, Mr. Chairman, will be given by Mr. William H. Woodward.

Senator STENNIS. All right, I thank you very much. This has been splendid. I did not know that you had Mr. Cortright listed here a while ago when you mentioned the matter about something further on the geodetic and observational satellites.

Mr. RHODE. Would you like to hear from Mr. Cortright?

Senator STENNIS. Yes.

Come around, Mr. Cortright.

TESTIMONY OF EDGAR M. CORTRIGHT, CHIEF, ADVANCED TECHNOLOGY PROGRAM, NASA—Resumed

Mr. CORTRIGHT. There is a meteorological satellite which originated in the Department of Defense and is classified. I have two charts to give you a quick look, if you wish. This is the satellite. It is 40 inches in diameter, and will weigh approximately 250 pounds. As you can see by looking at it, it is considerably more complicated than the simple vehicle which we have been used to in the past.

It has two television cameras looking out the bottom, and two sets of radiation detectors, that is, two types of radiation experiments on it. The data are recorded remotely, stored on tape, and when the satellite comes into view of large antenna read-out stations, the data are extracted from it.

This is roughly how it will work. It will be fired from the Atlantic Missile Range, and will go into a rather high inclination orbit of 51 degrees which will look like this. Now, each time it is interrogated, it is pre-scheduled to take more pictures during the next orbit. A typical sequence might look like this. The camera takes pictures in this region; the pictures are read out when the satellite comes into the view of the antenna. In addition, while it is in the view of the antenna, the pictures may be taken directly and the magnetic tape by-passed.

Then the satellite is instructed how to perform on the next orbit. It makes another orbit, takes some more pictures, and if it happens to miss an antenna, it makes another orbit until it can be interrogated at an antenna station. You have to keep up with it, know where it is and what it is doing at all times, and you instruct it as to how to take succeeding sets of pictures. One picture will be 800 miles on a side, and another picture right in the middle of it will be 65 miles on a side.

Despite its complexity, I would like to mention that it is purely an experimental type satellite. It will be nothing like an operational satellite. We will get a tremendous amount out of it, but it is just another experiment on the way toward a final system.

Mr. LEHRER. When do you expect to have that?

Mr. CORTRIGHT. This satellite, TIROS, will be launched, we hope, by the end of this year. There are two of them scheduled, one before the end of the year if possible, and the other one next spring. The meteorological satellites following TIROS will be of an even more complicated type. They will be stable, always looking toward the earth. This one spins which limits its utility.

The other question you asked yesterday concerned what advantage will the geodetic satellite have for location of ICBM targets. I have asked Dr. John O'Keefe to discuss that with you.

Senator STENNIS. *All right, Doctor, come around.*

TESTIMONY OF DR. JOHN A. O'KEEFE, ASSISTANT CHIEF, THEORETICAL DIVISION, NASA—Resumed

Dr. O'KEEFE. There were statements in the public press some years ago to the effect that there were geodetic discrepancies in the order of 15 miles. There were also statements to the effect that geodetic discrepancies were on the order of 1 mile. These are both false. The actual discrepancies are of the order of a thousand feet.

These are significant if the ICBM circular errors get to something of the order of a thousand feet, evidently. As a matter of fact, they are also significant when the ICBM errors get as small as two or three times that, because the ICBM program is so much more expensive than the geodetic program that a small saving in the ICBM program will pay the cost of the geodetic work.

The actual situation is that planned ICBM probable errors that are being considered are in the bracket of 1,000 or 1,500 feet at the present time. So that the situation, in summary, is that although the geodetic errors are small, yet the ICBM people are looking toward accuracies of their missiles such that these small geodetic errors become significant.

Senator STENNIS. Do you have any questions?

Mr. LEHRER. How much improvement will we get in our geodetic accuracy as a result of the satellite?

Dr. O'KEEFE. The improvement will be of the order of a thousand feet in some cases.

Mr. LEHRER. From an error of a thousand feet that exists today, you expect to get it down to zero?

Dr. O'KEEFE. Oh, no. We expect to reduce it from something like a thousand feet to something like a couple of hundred feet.

Mr. LEHRER. That is an improvement of 10.

Dr. O'KEEFE. An improvement by a factor of five.

(At this point in the hearing, a presentation was made on nuclear propulsion for air breathing engines. A short, unclassified synopsis of this presentation follows:)

TESTIMONY OF WILLIAM H. WOODWARD, CHIEF, POWERPLANTS RESEARCH DIVISION, NASA

The reasons why we want to apply nuclear energy to aircraft are obvious. They are unlimited range and long endurance. The problems that are involved are in many cases unique. Many of them are still unsolved, and all of them are difficult.

When one is talking about nuclear energy for aircraft, one generally is speaking of two categories of application. One, the direct air cycle; and the other, the indirect air or closed heat exchange system.

In the direct air cycle such as I have illustrated here in this illustration the air comes in the front of a turbojet, and passes directly through the reactor, then through the turbine and on out the exhaust nozzle. Hence the name "direct air cycle." The heat from the nuclear fuel is added to the air by conduction. The nuclear fission takes place within the reactor. The gray area around the reactor represents the shielding that is required to protect the aircraft and the crew.

In the indirect system or the closed heat exchange system, shown in the next illustration, the air that is picked up and fed into the entrance of the turbojet engine does not go through the reactor at all, but through a heat exchanger or radiator and on out the exhaust nozzle. The heat is brought from the reactor into the heat exchanger by means of a closed heat exchange loop.

This is quite similar to a hot water heating system in a house where the combustion takes place in the furnace, and the heat is transferred from there to the rooms by a hot water radiator.

The fluids that we can use in the heat exchanger can be liquids or gases. If they are liquids, because of the temperature levels we want to run, they are usually a metal, like sodium or potassium. Or, one has an option of also using a gas such as helium.

These two systems and the various ways we can apply them both have advantages, and they also have certain disadvantages. For instance, in the direct air cycle, because air is a poor absorber of heat, the reactor has to be be fairly large, so that we can get enough heat from the reactor into the air. Since the reactor is large, then the shield is large, and heavy, and this results in a fairly heavy system.

Furthermore, because hot air is coming from the reactor exit at high temperatures, we have to protect the internal parts of the reactor from oxidation or attack by oxygen. Mr. Ault showed you a little puff of smoke showing the result of a very high temperature oxygen attack on tungsten.

The indirect or the closed heat exchange system can run at lower temperatures. This is because the heat transfer fluid, the liquid metal or the gas that we have in the closed heat exchange loop, is a superior absorber of heat. Consequently, this reactor can be smaller.

If it is smaller, that is to our advantage, because then the shield can be smaller and we have a device that is lighter. There is not a clear gain because we have an extra piece of equipment in a heat exchanger and a pump that has to pump the liquid metal or gas.

Another problem of importance results from the fact that liquid metals attack the structural materials from which the reactor and engine parts are made. This attack by liquid metal can be as disastrous as oxygen attack.

More specifically, the problem areas that research is benig undertaken in are listed in the next illustration. The area of high temperature materials reflects the need for materials which can operate at high temperatures in air, or materials that can operate compatibly with a liquid metal or a gas at relatively lower temperatures.

The next problem area is shielding. The shields that I have shown here are large and bulky. We would like to get them as light as possible. The whole system is almost too heavy, so any weight reduction we can achieve is helpful.

Radiation effect on materials is something that has not been mentioned here before today. It simply means that when a material, let's say a lubricating oil, is exposed to the radiation from a reactor, one may end up with gunk, and no lubricating oil.

Some materials are very responsive to radiation; some are not. Of the ones that are, there are a few that can be altered and improved. We now have some lubricating oils that can withstand radiation levels that 2 or 3 years ago we did not feel were possible.

The next area is reactor physics and engineering, and this has to do with design of the reactor. Unfortunately, a reactor which is designed for the minimum compactness or, rather, the most compactness, from a reactor operation viewpoint, is not always the best design for trying to get the heat out. Consequently, compromises must be made.

Lastly is an area which I am not sure we could call a research problem, but is something that should be mentioned. This in the integration of the reactor and its control systems, and the engine and its control systems, all together into an airplane.

These integrated system problems are perhaps not research problems, but they are time consuming and they have to be started sufficiently well in advance so that all phases of the airplane are completed at the same time.

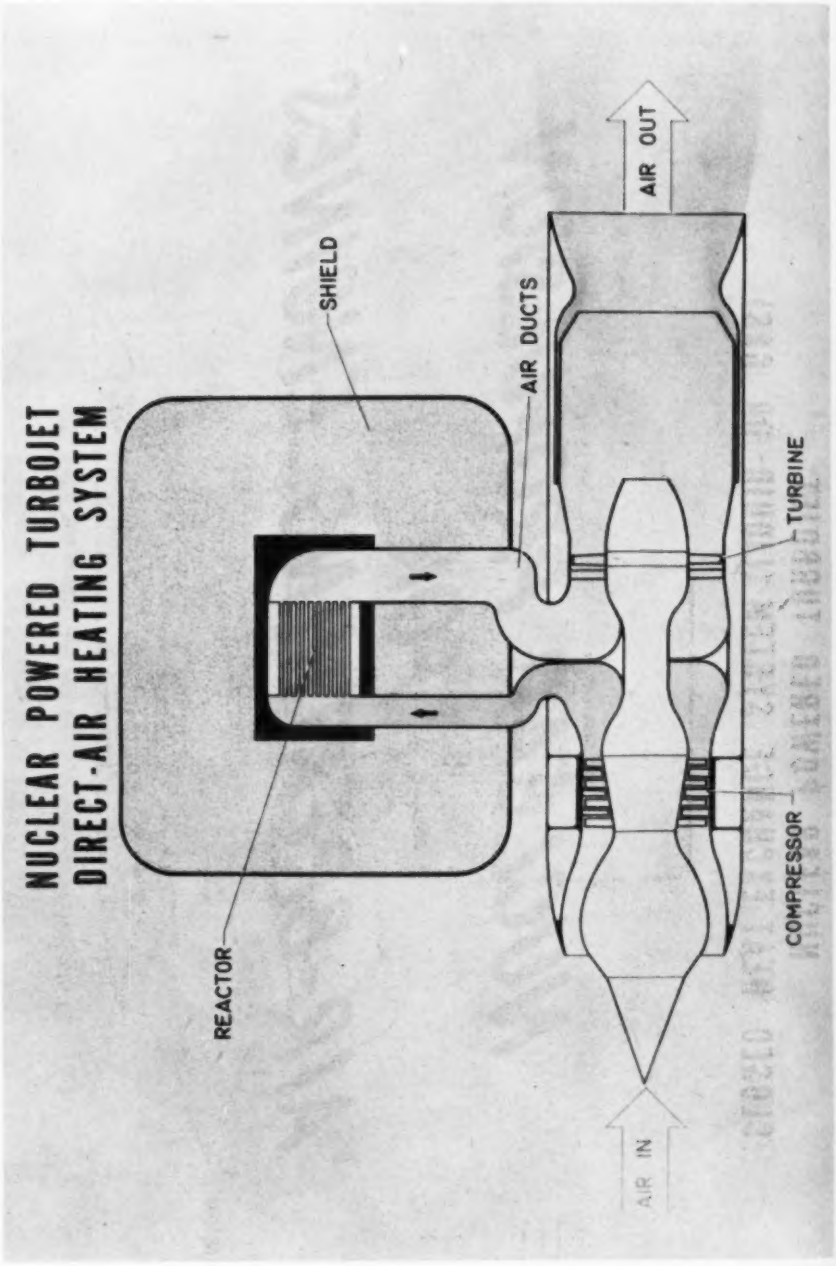
I have talked a little about the problems, and now I would like to compare the nuclear system with some of the more conventional systems to give you some perspective as to the overall picture.

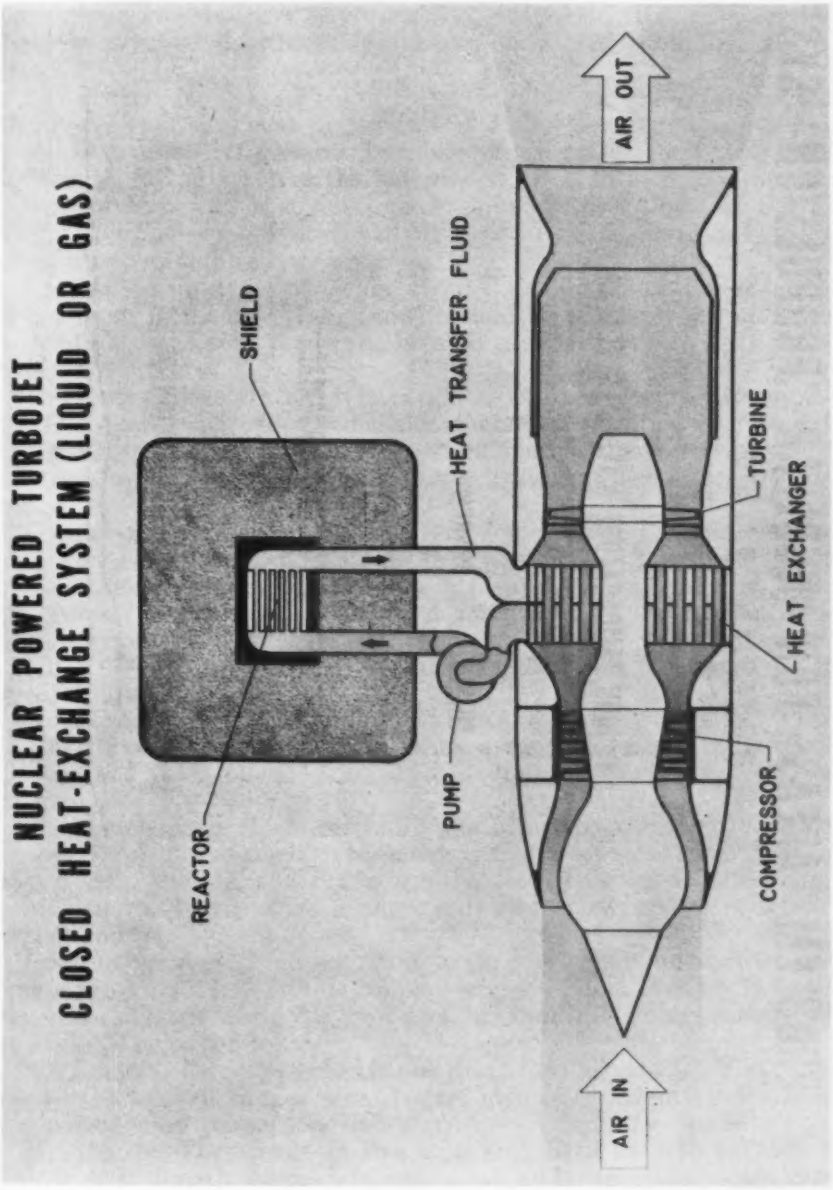
I am comparing now an advanced system (the chemically fueled), which has been in existence for quite a while with a system that is just in its infancy, so the comparison should be drawn with some care.

Conventional airplane engines using chemical fuels as a source of energy can carry a payload of 20 percent of their gross weight for a distance of 7,000 miles at speeds on the order of 500 miles per hour. This value decreases with increasing speed due to aerodynamic heating. The airplane structure and engines become heavier in order to withstand the heat. At some high speed, the conventional airplane's structural engine weight becomes so large that there is no room left for payload.

Estimates of the performance of the direct and indirect cycle nuclear-powered aircraft show that potentially the nuclear aircraft, either turbojet or turboprop powered, can surpass chemically fueled aircraft in payload capability over a wide range of speeds. Current technology does not yet allow us to achieve this performance. However, current technology will permit the design and construction of a subsonic airplane of substantial payload capability.

NUCLEAR PROPULSION FOR AIR-BREATHING ENGINES


NUCLEAR POWERED TURBOJET
DIRECT-AIR HEATING SYSTEM
SHIELD
AIR DUCTS
AIR OUT
TURBINE
REACTOR
COMPRESSOR
AIR IN


NUCLEAR POWERED TURBOJET
CLOSED HEAT-EXCHANGE SYSTEM (LIQUID OR GAS)
SHIELD
HEAT TRANSFER FLUID
AIR OUT
TURBINE
HEAT EXCHANGER
REACTOR
PUMP
COMPRESSOR
AIR IN

PROBLEM AREAS FOR NUCLEAR PROPULSION SYSTEMS

1. HIGH TEMPERATURE MATERIALS RESEARCH

2. SHIELDING RESEARCH

3. RADIATION EFFECT ON MATERIALS

4. REACTOR PHYSICS AND ENGINEERING

5. INTEGRATED SYSTEM PROBLEMS

Senator STENNIS. Thank you very much. Are there any other questions now?

I am very much intrigued by a great deal of this testimony, and this part about airplanes and the problems with reference to the metals—all of those presentations. It looks like we are getting a preview of something here, although you do not know just what will finally emerge. Is there anything else you would like to say now? Is there anyone who wishes to make an additional point here in the record?

Mr. RHODE. No, sir. I think this concludes our presentations for the day. I am sure that by the end of our presentations tomorrow, I will have every desire to congratulate you, Mr. Chairman, and your colleagues, for having had the patience to listen to us to this extent.

Senator STENNIS. It is our privilege, in the first place, and it is very, very interesting, in the next place, and I think it will be helpful to us in understanding your program.

I was just thinking a while ago about these line items, the different dollar items in the bill—it certainly should be relatively easy now to understand what your needs are, because they will be related to these various programs.

Mr. RHODE. You certainly have given us some very nice compliments. You mentioned our dedication and our devotion to duty. I think this goes for you too, sir. I think that you have shown every devotion to your duty in sitting through these presentations to this extent.

Senator STENNIS. I think I am very fortunate to come in contact with you gentlemen and to be on this committee. I really did not realize the extent of your accomplishments, your plans, and your programs. The Langley Research Center is right down near Norfolk, is it not?

Mr. RHODE. Yes, sir. It is 140 airline miles from Washington. It takes 50 minutes to go there.

Senator STENNIS. I would like very much to go down there.

Mr. RHODE. We would be glad, sir, to arrange for a trip to Langley for you and your colleagues at any time that you would like to have us do so.

Senator STENNIS. I am certainly going to recommend that we go down. I would like for it to be under ordinary circumstances, just to take a look, you see, and try to get the feel of things a little more.

Mr. RHODE. You just let us know your desires, sir, and we will take care of you.

Senator STENNIS. I do not want to go into this wind tunnel now where you blew a hole in this copper weight. [Laughter.] You say this little particle was going how fast, 8,000 miles? The pressure on it was 8,000 miles per hour.

Mr. LEHRER. Could you clarify one thing for the record. You mentioned the construction of wind tunnel models of aircraft. What is the size of wind tunnel models?

Mr. RHODE. They range in size from tiny little models, perhaps a half-inch in length, to models which are as large as full-scale airplanes. This depends on the wind tunnel test which we wish to perform, and the kind of a wind tunnel that we have to use. In the

extremely high hypersonic wind tunnels, we use the smaller models; and in the slower wind tunnels we can use the larger models.

Senator STENNIS. In giving a little review here of the preparation and presentation you have made, I do not want to leave out the staff member, Mr. Lehrer, and his associates on the staff, who have worked on this preparation with all of you gentlemen. He has certainly been of great value to the committee.

If there is nothing further, I am going to ask my friend Wilson, from Mississippi, which one of these models he is going to volunteer to give me as a souvenir of his testimony, and then we will adjourn.

Mr. RHODE. Would you permit us, sir, to use these models in our presentation before the House of Representatives first?

Senator STENNIS. Oh, yes, certainly.

We will take a recess until 10:30 tomorrow.

(Whereupon, at 5:35 p.m., the subcommittee recessed, to reconvene at 10:30 a.m., Friday, April 10, 1959.)

[Executive hearing as cleared by the National Aeronautics and Space Administration—Classified information deleted]

NASA AUTHORIZATION FOR FISCAL YEAR 1960

FRIDAY, APRIL 10, 1959

U.S. SENATE,
NASA AUTHORIZATION SUBCOMMITTEE OF THE
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10:45 a.m., in room 224, Old Senate Office Building, Senator John Stennis presiding.

Present: Senators Stennis, Cannon, Martin, and Smith.

Also present: Max Lehrer, assistant staff director; Dr. Glen P. Wilson, chief clerk; and Dr. Earl W. Lindveit, assistant chief clerk.

Senator STENNIS. This morning we will continue with the hearings on the NASA authorization request for the fiscal year 1960. Today's hearings are being held in executive session because they involve classified information dealing with manned hypersonic vehicles and missiles. However, a complete transcript will be made and we will expect NASA to review this transcript and delete only those matters which cannot be disclosed for security reasons. The sanitized testimony will then be incorporated in the printed record all of which will be released publicly as quickly as possible.

Our witnesses will again be introduced today by Mr. Richard V. Rhode, Assistant Director of Research for NASA for aircraft operating problems, structures and materials.

Mr. Rhode, you have already been sworn but you have other witnesses. May I call them out and please stand and all be sworn together.

Mr. Becker, Mr. Anderson, Mr. Drake, Mr. Williams, Mr. Ames, Mr. Allen, Dr. Houbolt, and Mr. Stone.

Do you and each of you solemnly swear that your testimony in this hearing will be the truth, the whole truth, and nothing but the truth so help you God?

Mr. BECKER. I do.
Mr. ANDERSON. I do.
Mr. DRAKE. I do.
Mr. WILLIAMS. I do.
Mr. AMES. I do.
Mr. ALLEN. I do.
Dr. HOUBOLT. I do.
Mr. STONE. I do.

(The biographical sketches of the witnesses follow:)

JOHN V. BECKER, CHIEF, SUPERSONIC AERODYNAMICS DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John V. Becker is Chief of the Supersonic Aerodynamics Division of NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1936 at the Langley facility.

Born in Albany, N.Y., in 1913, Becker earned a bachelor of science degree in mechanical engineering and a master of science degree from New York University in 1935 and 1956.

Becker joined the staff at Langley as a junior aeronautical engineer. He was appointed head of the 16-foot high-speed tunnel in 1943. He was named Assistant Chief of the Compressibility Research Division in 1947 and Chief of the Division in 1955. This Division was subsequently renamed Supersonic Aerodynamics Division.

In 1955, Becker was cited by New York University as one of its 100 outstanding graduates of the College of Engineering. He is an associate fellow of the Institute of the Aeronautical Sciences.

Mr. and Mrs. Becker and their two daughters live at 28 Oakland Drive, Newport News, Va.

ROGER A. ANDERSON, HEAD, AIRFRAMES COMPONENTS BRANCH, STRUCTURES RESEARCH DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Roger A. Anderson is head of the Airframes Components Branch of the Structures Research Division, NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, at Langley facility in 1944.

Born in Eveleth, Minn., in 1922, Anderson was awarded a bachelor of science degree in civil engineering by Northwestern University in 1944.

Anderson joined the Langley staff as a structural engineer in the Structures Research Division. He was associated with the Aeronautical Research Institute of Sweden from April 1948 to March 1949, returning to Langley as an aeronautical research scientist.

Anderson's principal research has been in stability and strength analysis of structures, with recent emphasis on problems arising from aerodynamic heating.

Mr. and Mrs. Anderson and their four sons live at 22 Barbour Drive, Warwick, Va.

HUBERT M. DRAKE, ASSISTANT CHIEF, RESEARCH DIVISION, HIGH-SPEED FLIGHT STATION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Hubert M. Drake is Assistant Chief of the Research Division at NASA's High-Speed Flight Station, Edwards, Calif. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, at the Langley Research Center, Langley Field, Va., in 1943.

Born in Brooklyn, N.Y., in 1921, Drake earned a bachelor of science degree in aeronautical engineering from the University of Michigan in 1943.

At Langley, Drake was assigned to the preflight tunnel. He was transferred to the High-Speed Flight Station in 1957. He has specialized in research in stability and control, and the human factors involved with advanced research airplanes.

Drake served on NACA technical subcommittees and is currently a member of the NASA Research Advisory Committee on Control, Guidance, and Navigation. He was a member of the Working Group on Human Factors of the NACA Special Committee on Space Technology. He is now a member of the joint High-Speed Flight Station-Air Force Flight Test Center X–15 Flight Test Steering Committee.

Mr. and Mrs. Drake have three children.

WALTER C. WILLIAMS, CHIEF, HIGH-SPEED FLIGHT STATION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Walter C. Williams, is Chief of the NASA's High-Speed Flight Station at Edwards, Calif. He directs high-speed flight research efforts encompassing flight investigations of many of the Nation's most advanced experimental aircraft.

Williams is a native of New Orleans, La. He was awarded a bachelor of science in aeronautical engineering degree from Louisiana State University in 1939.

After several months with the Glenn L. Martin Co., he joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, at the Langley Aeronautical Laboratory in 1940.

In 1946 he was made X–1 aircraft project engineer and was sent to Muroc (now Edwards) Air Force Base, Calif. When the NACA established its High-Speed Flight Station 1 year later, Williams was named Chief of the facility.

Williams is the author of numerous research articles. He is an associate fellow of the Institute of Aeronautical Sciences. His home is at 44874 11th Street, W., Lancaster, Calif.

MILTON B. AMES, JR., CHIEF, AERODYNAMICS AND FLIGHT MECHANICS RESEARCH DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Milton B. Ames, Jr., was appointed Chief of the Aerodynamics and Flight Mechanics Research Division at the headquarters of the National Aeronautics and Space Administration after the NASA was established on October 1, 1958. Previously he was Chief of the Aerodynamics Division of the National Advisory Committee for Aeronautics in Washington.

Ames is a native of Norfolk, Va. He earned a bachelor of science degree in aeronautical engineering from Georgia Institute of Technology in 1936.

He joined the staff of the NACA in 1936 as an aeronautical research engineer at the Langley Aeronautical Laboratory. From 1941 to 1943 he was engineering assistant to the NACA Director at headquarters. For the next 3 years he was engineering assistant to the Chief of Military Research in Washington. In 1946 he was appointed Chief of the Aerodynamics Division. During his career, he has specialized in research on aircraft wing flaps and design of airplane controls.

Ames is a fellow of the Institute of the Aeronautical Sciences, and is author of numerous technical publications.

Mr. and Mrs. Ames and their three children live in Alexandria, Va.

H. JULIAN ALLEN, CHIEF, HIGH-SPEED RESEARCH DIVISION, AMES RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

H. Julian Allen, Chief of the High-Speed Research Division, at the NASA's Ames Research Center, Moffett Field, Calif., is an authority on the aerodynamics of long-range missiles, and on the design of transonic, supersonic, and hypersonic wind tunnels and test facilities. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1936.

Born in Maywood, Ill., in 1910, Allen is an engineering graduate of Stanford University.

He joined the NACA as a junior aeronautical engineer at the Langley Research Center, Langley Field, Va., in 1936. He was transferred to the Ames facility in 1940 as an aeronautical engineer. One year later he was named Chief of the Ames Theoretical Aerodynamics Branch. He has been in his present position since 1945.

Allen was awarded the Sylvanus Albert Reed award for 1955 by the Institute of the Aeronautical Sciences "for contributions and leadership in solving problems in the design of supersonic airplanes and missiles, especially the thermal problems at hypersonic speed."

Allen is a fellow of the Institute of Aeronautical Sciences and former chairman of the San Francisco section. He is also a member of Sigma Xi.

JOHN C. HOUBOLT, ASSISTANT CHIEF, DYNAMIC LOADS DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John C. Houbolt has been Assistant Chief of the Dynamic Loads Division at NASA's Langley Research Center, Langley Field, Va., since 1949. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA at the Langley facility in 1942.

Born in Des Moines, Iowa, in 1919, Dr. Houbolt earned bachelor and master of science degrees in civil engineering from the University of Illinois in 1940 and 1942. In 1958 he was awarded the degree of doctor of technical sciences by the Swiss Federal Institute of Technology, Zurich, Switzerland.

Dr. Houbolt joined the Langley staff as an assistant civil engineer in the Structures Research Division. In 1949 he was appointed to his present position where he directs research in aircraft flutter, vibration, and noise, flight through gusty air, and the loads encountered in landing and taxiing.

In 1956 Dr. Houbolt received the Rockefeller Public Service Award given annually to the outstanding career civilians in the Federal Government. The award permitted him to undertake advanced studies in the fields of aeroelasticity and aerotherodynamics at the Swiss Federal Institute of Technology.

He is a member of Tau Beta Pi, Chi Epsilon, Phi Kappa Phi, and Sigma Xi. For the past several years he has been an instructor at the University of Virginia's Engineering Graduate Extension School in Hampton, Va.

Dr. and Mrs. Houbolt (the former Mary Morris) and their three children live at 23 North Greenfield Avenue, Hampton, Va.

DAVID G. STONE, HEAD, STABILITY AND CONTROLS BRANCH, PILOTLESS AIRCRAFT RESEARCH DIVISION, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

David G. Stone is Head of the Stability and Controls Branch of the Pilotless Aircraft Research Division, NASA's Langley Research Center, Langley Field, Va. He joined the National Advisory Committee for Aeronautics, the predecessor of the NASA, in 1941.

Born in Pocatello, Idaho, in 1919, Stone earned a bachelor of science degree in aeronautical engineering from the University of Washington in 1941.

For a short time following graduation, Stone was on the staff of the Curtiss Aeroplane Division in Buffalo, N.Y. In November 1941 he joined the NACA at Langley as a junior aeronautical engineer at the 19-foot pressure tunnel facility. He was transferred to the Pilotless Aircraft Research Division in June 1946, and was appointed to his present position shortly after.

Stone is a member of the Engineers Club of the Virginia Peninsula. He, his wife, and daughter live at 122 Villa Road, Newport News, Va.

Senator STENNIS. Mr. Rhode?

Mr. RHODE. Thank you, Mr. Chairman. Yesterday, as you may recall, we effected something of a transition in our program from discussions of planned space projects to discussions of research being conducted in our research centers.

We also brought out that NASA has responsibility not only in the field of astronautics but in the field of aeronautics. For that reason we presented a segment of our program yesterday which had to do with aircraft. Today we will continue our discussions of the research activities in our various research centers, and the discussions, as you have already stated, sir, have to do with manned hypersonic vehicles and with missiles of all kinds, guided as well as ballistic missiles.

Our first speaker today is Mr. John V. Becker who is Chief of the Supersonic Aerodynamics Division at our Langley Research Center.

Senator STENNIS. Come around, Mr. Becker. We are glad to have you, and while you are getting oriented there with your charts we will go off the record.

(Discussion off the record.)

Senator STENNIS. All right, Mr. Becker.

TESTIMONY OF JOHN V. BECKER, CHIEF, SUPERSONIC AERODYNAMICS DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. BECKER. I will start by explaining what we mean by hypersonic. This term has come to mean any speed greater than about 1 mile per second. You will recall that the satellite vehicles travel about 5 miles per second. They are one of the class of manned vehicles——

Senator STENNIS. Pardon me, hypersonic means more than 1 mile per second?

Mr. BECKER. More than 1 mile per second. That is 3,600 miles per hour.

Another type of hypersonic vehicle of the manned type in which we are interested is the Dynasoar class.

AERODYNAMIC PROBLEMS

In this first chart we have tried to show the main features of these hypersonic vehicles as they compare to the more familiar supersonic bombers which you have heard about before. For a vehicle which has to carry its own fuel and its own propulsion system and cover the whole range under its own power, we find a design similar to the B–70, say; this is a very large airplane because it has to have enough thrust, enough power, to get off the ground with the large fuel load.

Now, in the case of the hypersonic glider, the glider itself carries no part of its propulsion system. The propulsion is provided by a large booster of the ICBM class, say, and the engine then falls off after giving the glider enough speed to coast the entire distance of its flight. Because it does not have to carry any propulsion equipment, and because it carries no fuel, it is a small relatively simple vehicle aerodynamically speaking as compared to the older type.

To achieve the long ranges in which we are interested, we have to boost our glider to extremely high speeds. To achieve really long ranges you have to have a speed that is getting up close to the satellite speed. So from the research standpoint we are interested in getting into that extremely high-speed range, whereas previously we were concerned with aerodynamics at much lower speeds.

The other point made here is that the higher the speed of the glider, the higher the altitude at which it starts its flight. If it goes all the way to satellite conditions, it is essentially out of the atmosphere. For the global range we operate in the upper fringes of the atmosphere. The main problem area, of course, is aerodynamic heating. and we will say more about this a little later.

In the field of stability and control for these gliders, the problems really arise from two main sources. First, the glider has to cover an extreme speed range starting off near the satellite speed, gliding down through the atmosphere, and finally landing. It has to be stable and controllable in all of those regimes.

Corresponding to the high-speed range, we have a large range of altitude. At the highest altitude we have not enough aerodynamics to control the vehicle and we use what is called reaction controls, which you will hear more about later.

Finally, of course, we have to land the vehicle. During boost there is a special class of stability and control problems that we are not familiar with for the ordinary aircraft.

One of the main problems in an airplane of the B–70 type was drag reduction. This is a problem for the gliders, but to a reduced extent.

If we consider a 5,000-mile-range glider, its initial speed will be high enough so that as it circles around the curved path it has a centrifugal lift force. Thus, we don't have to provide all of the lift aerodynamically. There is enough aerodynamic force here to show that we are concerned to some extent with drag, and we have to use a design which has low drag. An illustration of that type of design is this model here. It has to be very long, slender. It has to have sharp leading edges. It has a long slender fuselage and has to have controls.

Now, if we are aiming for global range, then the centrifugal lift that comes from flying around the curved path is so large that the aerodynamic forces we are concerned with become very small. With these small aerodynamic forces we are less concerned about the drag and we can design vehicles which have in general shorter more stubby shapes with blunt leading edge radii which are better structurally.

So if we are trying for the extreme ranges on the order of global, we have really a different kind of vehicle than if we are aiming for the shorter ranges. By short range I mean up to 5,000 miles. The Dynasoar vehicle is actually in between these two extremes. It will start with short ranges and its range can gradually be increased.

DIRECTIONAL STABILITY

To illustrate the stability problems of these vehicles we have considered here the directional stability. By directional stability we mean the ability of the vehicle to keep itself pointed along the desired flight path. If the directional stability diminishes down into this yellow region here, the glider will tend to yaw abruptly and this may be catastrophic as it was in the case of the X–2. The X–2 research airplane had this characteristic shape of its directional stability curve and was lost in this region.

Many current airplanes tend to have this stability characteristic. That is, if the speed is increased far enough, we reach a point of directional instability. Now, in these hypersonic gliders, by proper aerodynamic design it appears that this trend can be avoided, and that stable configurations can be achieved all the way up to the very high speeds that we are interested in.

Now, you will notice that the upper extent of these curves is dashed, meaning that we have only calculated the performance in this area. One of the needs at present is to verify this type of calculation with actual experimental work.

We have equipment under procurement which will enable us to do this. The X–15 will contribute importantly in flight research in filling in a part of this unknown region by answering a part of this question.

AERODYNAMIC HEATING DURING DESCENT

Now, let me say heating is the main problem, and to give you a little feel for the problem we have considered some actual trajectories here along which our gliders might reenter the atmosphere. These are presumed to be global-range gliders descending to a landing. The glider presumably started its flight over here, came all the way around the earth in the outer fringes of the atmosphere, and in its last few thousand miles of flight it will reenter the atmosphere.

We may follow different paths in reentering. If we operate the glider at a low-lift coefficient or a low attitude, it will glide along a path such as shown and will have a relatively long range in the atmosphere and a long time in the high heating region.

If we fly at a high angle of attack with more drag, the glider will come down more quickly, but it will have to pass through the same point of critical heating which occurs at about 15,000 miles per hour.

It will be in this situation a shorter time than if it glided with low drag. In general, in the design of these gliders the structure has to be designed to cope with this critical point here, and at all other points in the glide the structure has a less serious problem than at that particular point.

Presumably these wing vehicles will carry landing gears as in the case of Dynasoar, and they will be able to make a conventional airport landing. The accelerations encountered by these vehicles are quite low, of the order of a half to 1 G. acs compared to perhaps 8 G. for our Mercury capsule.

REENTRY OF SATELLITE VEHICLES

In this chart we consider the manner in which a satellite vehicle, a manned satellite vehicle, might reenter. The speed initially is comparable to the speed of our global range glider, but there is in general one important difference here in that the satellite vehicle will reenter at a finite small angle with respect to the atmosphere. That is instead of being tangential, it is aimed down into the atmosphere.

Our Mercury vehicle at 3 degrees reentry angle would follow a path indicated here. It would encounter something like 10 G. deceleration. Our lifting vehicle coming in along the same path might follow one of two courses.

If the attitude of the vehicle remained the same, that is if the pilot did not exert any control, the vehicle would skip out of the atmosphere, then fall back in again and follow a skipping path much as a stone skips on water, and at each point of penetration we would have a region of high heating.

Another way in which we might reenter, instead of allowing it to skip, if control is exercised at this point in the flight path, the glider can then be made to join the same kind of glide path which we showed for the global range glider, in which an equilibrium glide with no skipping occurs.

There are two regions of high heating, one in this point of initial penetration and then later in the glide the same critical point that we noted before. We can understand this heating problem a little bit better from the standpoint of energy considerations perhaps. In this

chart we also consider the gliders and the ballistic vehicles all starting with essentially satellite velocity.

We see that if we consider all of the energy due to the velocity of these vehicles and convert that into heat, we have 140 million units of heat or British thermal units. That number is equivalent to the amount of heat used during a 1-year period in an ordinary small dwelling.

In the reentry period, all of this heat is generated in a few minutes. Now if this large amount of heat energy, was applied to the vehicle itself, it would melt and vaporize. But fortunately in passing through the atmosphere the vehicle heats the atmosphere in addition to becoming heated itself, so that only a part of the heat generated, the part indicated in the bottom side of this chart, actually penetrates the vehicle. This is what we have to design for.

The chart shows that by increasing the bluntness of our vehicle and giving it a flat entry path, we can transfer more heat to the atmosphere. In the case of our Mercury capsule again, 99 percent of the heat that is generated is absorbed by the atmosphere, and only 1 percent actually flows into the vehicle. Now in relation to the amount of heat that we can absorb readily in the metal skin of the Mercury vehicle, we have shown only about 10 percent here, so that by devoting 10 percent of the weight of this vehicle to heat protection, it can survive the reentry. But if we look at our winged machines which have much larger frictional areas, they are less blunt, the heat loads here are so high that they cannot possibly be absorbed in the metal, and some other mechanism has to be used for these winged airplanes to enable them to survive reentry.

The mechanism that is used is radiation. Heat is radiated away from the metal skin provided we let the skin get hot enough. This requires metal temperatures of the order of 2,000° over much of the vehicle, and it presents a very serious design problem about which you will hear in the next talk.

At critical points on these vehicles, the nose of the fuselage, the wing leading edges, and the leading edges of the controls, the temperatures required to radiate the heat is even higher than 2,000 degrees, and in these areas of the airplane we have to use materials such as ceramics or ablating materials or something other than the superalloy metals.

In conclusion we have painted a general picture of these difficult problems, but I would like to leave you with the idea that the more we look into these vehicles, the more they appear clearly feasible. There is no fundamental problem here that cannot be solved by continued research and development.

Senator STENNIS. That is an encouraging statement, very good. Senator Martin, do you have some questions?

Senator MARTIN. He answered my question whether it has been reduced down enough for the heat and number of G.'s to make this a feasible and practical operation.

Mr. BECKER. We have had two companies working on the Dynasoar project and they have in the past year gone into this problem of structural heating in great detail, and they have come up with two practical solutions. All of the "bugs" are not worked out of these solutions yet. There are still many questions about some of the inputs that have to be made into their calculations from the heat transfer standpoint. In the case of a simple vehicle like the Mercury capsule, we can predict the heating accurately. We know this from our ICBM work. But in the case of a complex shape like these winged vehicles with controls, there is much to be learned about the manner in which the air flows and in which the heating actually occurs in the critical parts of the vehicle.

Senator MARTIN. Is that a model of the Dynasoar?

Mr. BECKER. A better model of the Dynasoar is that red one back there which you will see later. Dynasoar is actually intermediate between these two, the shorter range and the satellite vehicle. This model was intended to represent a small winged satellite vehicle carrying perhaps one man and its equipment.

Senator MARTIN. They have done a lot of work on materials and the capacity of materials to throw heat out rather than let it come into the Dynasoar or any other similar project, as I understand it.

Mr. BECKER. That's right.

Mr. RHODE. I might suggest, Mr. Chairman, that the next presentation is sufficiently closely related to this one, particularly in respect to the heating problem and the materials and structures problems, that it might be well to listen to the next paper and then take a break for questions at that point.

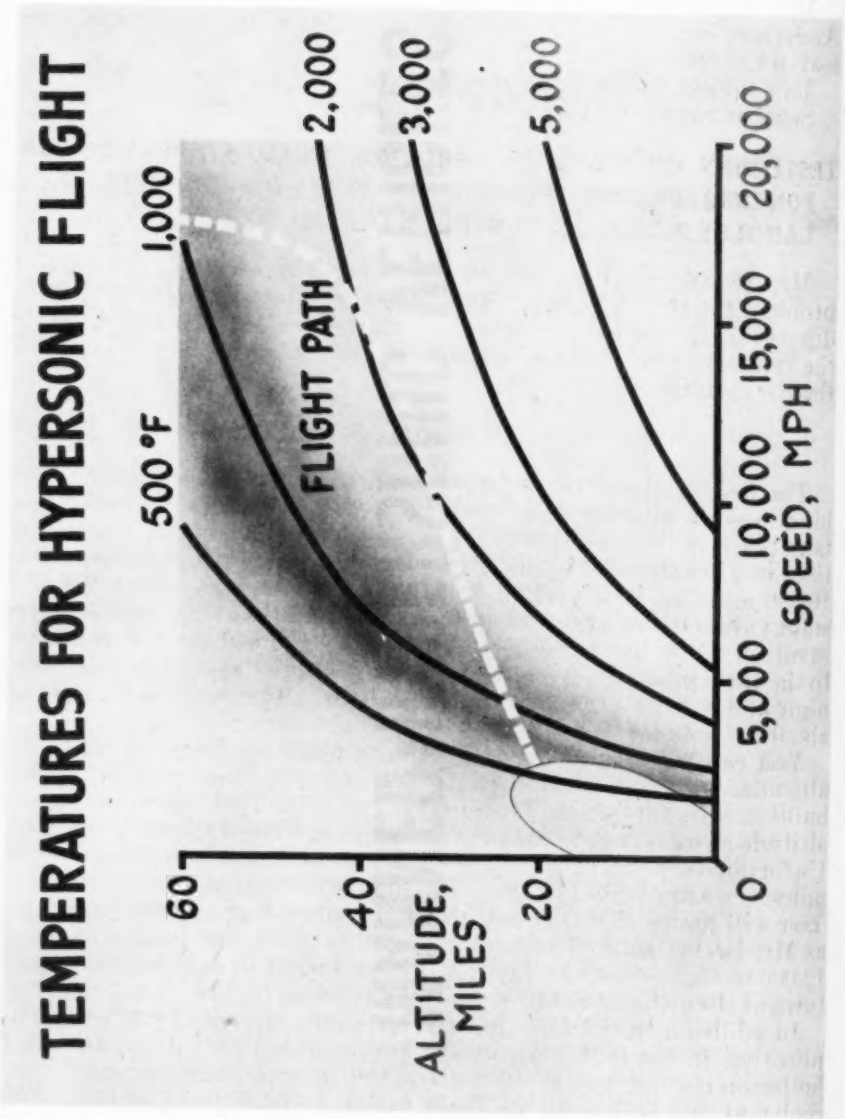
Senator MARTIN. What is the number of G.'s that you can consider within range of bringing them to operational?

Mr. BECKER. For the winged airplane?

Senator MARTIN. For the manned, yet. When you get below a certain point do you think you can harness it enough to make it fully operational?

Mr. BECKER. The Mercury capsule in returning will encounter at least 8 G.'s, and if you come in at a steep angle it will be more than that. This is an acceleration that is acceptable for test pilots, military pilots. In the case of the winged airplane, if the reentry is made tangential to the atmosphere, the G.'s are very low, ordinarily less than 1 G., which offers no aeronautical problems.

MANNED HYPERSONIC VEHICLES


TEMPERATURES FOR HYPERSONIC FLIGHT
500 °F
1,000
2,000
3,000
5,000
FLIGHT PATH
ALTITUDE, MILES
60
40
20
0
5,000
10,000
15,000
20,000
SPEED, MPH

Senator STENNIS. All right. Thank you, Mr. Rhode, you will be free to suggest the break points here on these matters without being called on. Thank you, Mr. Becker. Who do you have next, Mr. Rhode?

Mr. RHODE. Our next speaker, Mr. Chairman, is Mr. Roger A. Anderson, head of our Airframes Components Branch, Langley Research Center.

This subject will be structures for hypersonic vehicles.

Senator STENNIS. All right, Mr. Anderson.

TESTIMONY OF ROGER A. ANDERSON, HEAD, AIRFRAMES COMPONENTS BRANCH, STRUCTURES RESEARCH DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. ANDERSON. Our previous speaker introduced us to the heating problem for these vehicles. Now I will carry on with this subject by discussing the actual temperatures created within the structures of the vehicles by air friction, some of the problems and the ways to build these structures.

TEMPERATURES FOR HYPERSONIC FLIGHT

The first chart shows the temperature environment created by combinations of altitude and speed in which flight could conceivably take place in the atmosphere. The coloring indicates the appearance that an aircraft would have if it were flying at a given point, say at 10,000 miles an hour and 20 miles high. These lines shown are constant values of temperature and give you an idea of the temperatures involved. Now our present experience with manned aircraft is limited to the little green shaded area in the corner, a little more than 20 miles high and a little over 2,000 miles an hour. The X–15 will carry us about twice as far in speed.

You can see right away that if you try to go faster at these low altitudes we very quickly are in temperatures that we simply can't build a structure for. It appears, however, that by going up in altitude as we increase speed that we can get around the hottest region. Unfortunately there is very little air at altitudes of more than 60 miles so we are forced to operate along paths such as that shown here. You will notice that this path for hypersonic flight for vehicles such as Mr. Becker showed you intersects this 2,000° line in this range of 12,000 to 15,000 miles an hour, so we are forced to deal with temperatures of the order of 2,000° in building these airplanes.

In addition to the fact that the airplanes are hot, we have a complicating factor that vehicles are unevenly heated. They are much hotter on the bottom and they are cooler on top. They are also much cooler at the rear than they are up near the leading edges. This causes the vehicle to distort and bend and develops thermal stresses and thermal distortions. These factors give rise to a very difficult construction problem.

EFFECT OF TEMPERATURE ON MATERIALS

This next chart shows some of the materials that we are working with and how their strength falls off as temperature increases. Current airplanes are made of aluminum alloy and we see that their strength falls off very drastically as the melting point, around 1,100° is approached.

Similarly for stainless steel and nickel-based alloys their strengths also fall off as their melting points, around 2,500°, are approached. There are some refractory materials, molybdenum and silicon carbide, which are attractive for these vehicles. They are not very strong to begin with but their strength persists to high temperatures. There are a lot of problems in building vehicles with materials like this. They oxidize and so forth. I won't go into these, but one thing that we are always concerned about is weight. All of these materials are at least 2 times as heavy as aluminum alloy. Because of this, these materials must be rolled into very thin sheets or the airplane will never get off the ground. To give you an idea of the thinness of these sheets I have a piece here that is eight one-thousandths of an inch thick. It is very strong in tension but does not have any bending stiffness or compression stiffness. As a consequence, we have to fabricate these thin sheets into new types of skin panels.

FABRICATION PANELS

The next chart shows the kind of panels that we are achieving. These skins don't look very thin here. The upper one is called a honeycomb sandwich panel. It has two very thin sheets separated by a core material which is cellular and very light in weight. Next, we have a construction that is similar to a cardboard box. These are types of construction that are needed for these high temperature materials.

They may be contrasted with the conventional aluminum alloy construction, shown below, which has relatively few stocky heavy parts put together with rivets.

The sandwich panels have to be welded together or brazed together. I have some samples here which indicate their nature and lightness. You may care to look at them afterwards. They are fairly complex and require thousands of feet of weld lines in an aircraft. These panels are enormously stiff. The same thin material is enormously stiff and strong. One of the problems in their use is their high cost. Aluminum panel like this conventional one might cost about $25 a square foot to manufacture while these sandwich panels run from several hundred to a thousand dollars a square foot. One of our objectives is to keep the cost of this construction within reason.

Senator STENNIS. What was that you said, it might run from a few hundred to a thousand dollars a square foot?

Mr. ANDERSON. Right, to manufacture the skin panels and the exterior surface of the airplane.

Senator STENNIS. That is to withstand the heat?

Mr. ANDERSON. The heat and to give the necessary stiffness to the thin gages of metal that we are dealing with.

Senator MARTIN. Are any of these more expensive?

Mr. ANDERSON. The one you have there is this honeycomb core, the one you have in your left hand; and the one you have in your right hand is a sample like this.

Senator STENNIS. While we are interrupting, who do you get to make this?

Mr. ANDERSON. There are several suppliers in this country. We make some of them ourselves, but they are produced commercially now.

Senator STENNIS. Do the aluminum people make some?

Mr. ANDERSON. The aluminum people don't make them, unfortunately. It is the steel people, and the aircraft fabricators. I can give you some names if you wish.

STRUCTURAL APPROACHES

Those panels are used in making the aircraft, and because of the heating problem we have really two basic approaches that are being investigated now. On the one extreme, we have what you might call an unprotected structure. It is right out in the airstream. It gets red hot and at the same time must carry the loads in this reduced strength condition. These conditions put maximum demands on material properties. Of course, the pilot and his equipment is packaged inside the vehicle in a pressurized and insulated compartment.

The other extreme, which is a little more novel, is to have an aluminum aircraft that is covered with insulation panels and has a cooling system to conduct water over the surface of the aircraft to keep it below 200°. That poses some very interesting construction problems because the outside panels get red hot while the aluminum alloy an inch away is only 200° and there is a terrific difference in expansion between these two skins. Therefore, we need these lines that you see here for expansion joints. I have a piece of hardware that has been produced by one of our companies on the table that illustrates this method of construction. The inside of this is just a typical aluminum construction, and glued to it are these cooling tubes for the water.

This package is an insulation package which lies on top of the aluminum structure. The whole thing is covered over with these panels which have expansion joints and which keep the heat away from the structure. The joints allow free expansion so as not to buckle.

By this technique, these panels become hot and radiate about 98 or 99 percent of the heat and 1 or 2 percent leaks through to the structure and is absorbed by the water. These kinds of construction are rather radical from the standpoint of present-day aircraft, so we have quite a few problems to solve in structural research. This chart is intended to indicate some of the kinds of tests that we go through in working on structures like this.

STRUCTURES RESEARCH

First of all we may take these structures and subject them to what we call a radiant heat test. We simulate the effects of the high temperature air by heating the structure with heat lamps such as the one I have here. This little lamp is an electric light bulb. The only difference really is that it absorbs about 3,000 watts or 4 horsepower to light it up and we may use several hundred of such lamps in a

single test to cover the aircraft and to simulate the heating environment. In such a test we simply measure the distortions of the structure and the manner in which the heat flows through it.

We also simulate the effect of the air forces by applying loads to the structure at the same time as we heat it. There we are concerned with measuring the structural strength and behavior under the combinations of load and heat.

There are certain problems that you simply can't look into in a simple laboratory. The structures interact with the air, and therefore we must do a certain amount of testing in wind tunnels. Here we take a structural part and pass a 10,000° airstream over it. We measure the temperature distribution in the model and the rate at which material melts and is carried away.

A final proof of all this laboratory work is of course the flight test. As an example of such tests, the chart shows the X–15 airplane which is to be flown this year. For structural research purposes, this airplane is instrumented with hundreds of thermocouples, pressure measuring devices, strain gages and devices that measure distortion of the structure. From these measurements, we hope to find out whether our laboratory work pans out, so to speak.

LEADING-EDGE PROBLEMS

I would like to deal very briefly with the problems that are associated with the leading edges which are very hot on these vehicles. We don't have materials that can withstand the heat generated without some special way of cooling the structure.

The chart shows four schemes for keeping the leading edges reasonably cool. In the first case the heat which comes in at the leading edge is conducted back through the metal and then is reradiated out on the sides. By this means, we hope to keep the leading edge cool enough to permit building it out of metal. It is a workable solution but unfortunately it is very heavy. I have a sample here. It is made out of niobium and it is a little too heavy to fly.

A second approach is to put a piece of ceramic at the leading edge and to take the brunt of the heat and radiate it out. The little bit that leaks through the ceramic is radiated out further back.

We have the difficult problem of attaching the ceramic block to a piece of metal. They have different coefficients of expansion, but it has the potential of being at least half as light or lighter than the first approach.

These last two approaches are different from the first two in that we use coolant materials actively instead of a passive defense against the heat. In the first of these, we pass a coolant material through tubes that are located inside the leading edge; sort of like a deicing system in reverse. The big problem here though is that the amount of heat that comes into the tube is very large and it is very difficult to radiate the cooling flow to keep the leading edge from burning up.

The last approach which is attracting a great deal of attention is called ablation. In this case, the cooling material is placed on the outside and is allowed to vaporize and melt as the heat is applied to it. These materials are solid and there are many types. I think we all know that this type of approach is being used to cool ballistic missile warheads.

I have some samples of the kinds of materials that we are testing at Langley. This one has the shape of a mercury capsule and was inserted into a 10,000-degree airstream. This one is a fluorocarbon known as teflon and this one is an entirely different kind of material. They behave quite differently. These are the type of results you get after they have been in such an airstream for about a half a minute. This teflon model is worn down considerably in relation to the other one. It is also very rough, which is of concern for aerodynamic reasons. But the point here is that by use of such materials we can achieve large heat capacities. These materials can absorb say from 5,000 to 10,000 B.t.u.'s per pound of material that goes away, relative to, say, a thousand B.t.u.'s per pound for boiling water.

In summary we might say that the major problem that we are concerned with for building hypersonic vehicles is the materials problem. This is where the breakthroughs are going to occur. We also have the problem of taking these new materials which have been relatively untried and using them in structural applications. Because of the interaction with other fields, aerodynamics and so forth, the best way to go about this problem is to do it on a cooperative basis with aerodynamacists, materials people and structural engineers.

Thank you.

Senator STENNIS. We thank you for these amazing facts. Now these tests you are talking about, were they made in wind tunnels?

Mr. ANDERSON. That's right; a hot wind tunnel.

Senator STENNIS. I have one question that relates back to something brought up a while ago. When you were talking about the range of the military aircraft a while ago, talking about a 5,000-mile range, do you mean a radius of 5,000 miles or the round trip?

Mr. BECKER. That is the total range.

Senator STENNIS. The total space traveled?

Mr. BECKER. These vehicles in general can't turn around and come back. The only way they can get back is to go all the way around.

Senator STENNIS. That is the way I understood it. And another question, How far along now have you gotten in proving this 99-percent installation or absorption of heat which you mentioned? Has that been thoroughly demonstrated to your satisfaction in your test tunnels and so forth?

Mr. ANDERSON. Yes, I would say it is. The only problem is we can do that at, say, the 2,000-degree level. If you want to radiate at the 2,500-degree level then you have got to have a material that can stand it, and this is where we are stopped right now.

Senator STENNIS. You are stymied on that but you do have it up to the 2,000.

Mr. ANDERSON. Right. We have the ability to radiate that amount.

Senator STENNIS. This is what you would call a good time for questions, isn't it, Mr. Rhode?

Mr. RHODE. My suggestion was, Mr. Chairman, that I thought that these first two papers were sufficiently closely related that this was a good time to ask questions about both of them.

Senator STENNIS. All right. Senator Martin?

Senator MARTIN. This 99-percent achievement—is it bringing you close enough to an operational result product so that you are looking ahead optimistically?

Mr. ANDERSON. Oh, yes, very much so. In other words, if the temperature at the surface does not exceed a critical value; we are fully capable of radiating heat up to about 2,000 degrees. When you get beyond that we have to have a material or a metalic or a ceramic surface that can stand these temperatures with reliability and be lightweight.

Senator MARTIN. And that is your principal objective right now.

Mr. ANDERSON. Finding materials that can do that.

Senator MARTIN. To further that range on materials development?

Mr. ANDERSON. That's right.

Senator MARTIN. That is about all I have.

Senator STENNIS. All right, Mr. Rhode, proceed. Thank you, gentlemen.

Mr. RHODE. We are now going to get away a little bit from the problems of the vehicle itself and start talking about the problems of the man that has to fly in these hot airplanes. Our next speaker will be Mr. Hubert M. Drake of the NASA High-Speed Flight Station at Edwards, Calif.

Senator STENNIS. All right, Mr. Drake. We are glad to have you, sir.

TESTIMONY OF HUBERT M. DRAKE, ASSISTANT CHIEF, RESEARCH DIVISION, NASA HIGH-SPEED FLIGHT STATION, EDWARDS, CALIF.

Mr. DRAKE. The general area that I am going to discuss pertains to the pilot and how he works together with his machine. So far this morning we have been hearing about the aerodynamic problems and the structural problems. Now I would like to discuss briefly a few of the human problems involved in the operation of such high-speed vehicles. This first chart indicates a few of the problem areas.

PILOTING AND CONTROL PROBLEMS

I don't have time enough to discuss them all so I won't go through them all in detail. However, the NASA has been working in all of these fields for a considerable length of time. I would like to start by taking up the first subject, that of the role of the pilot; that is, what he is doing in the vehicle and what he is contributing to it. This brings in the question of the proper tradeoff between the utilization of a pilot and automatic piloting equipment.

HUMAN VERSUS AUTOMATIC CONTROL

The automatic equipment is attractive because it has strength that the pilot does not have, it is quicker in response than he is, it is more precise in its response. However, automatic equipment has a considerable number of what one might call frailties: (1) Such equipment is extremely complex; (2) it lacks reliability; (3) it is expensive; and (4) it needs to be developed.

From the foregoing it is apparent that automatic equipment will always come later than the human pilot in the development cycle. Thus, the question of how much automaticity to incorporate in a given

airplane or space vehicle involves two elements, the present state of the art of automatic controls systems and the capabilities of the human pilot.

The NASA is conducting research in both of these fields; that is, exploring means of improving automatic equipment, its capabilities, and also exploring the limitations of the human pilot and his abilities. I will not go into detail on the automatic equipment research. However, when we consider the limitations of the human's abilities, we are faced with a real problem; namely, we would like to take advantage of the limits of the human ability but we prefer to explore these limits so that risk of the loss of life is eliminated.

This brings the problem of simulating these human limits investigations on the ground, and it brings us to our second item, which is simulation and training.

SIMULATION AND TRAINING

A flight simulator is a mechanical and/or electronic device that is used to imitate an actual airplane. This is done in the manner shown on this next chart. I will leave this one over here so I can refer back to that. We have here a pilot sitting in a cockpit mockup. This is called a stationary simulator because it does not move. The pilot has the usual controls and instruments on an instrument panel. When he moves the controls the electronic computer computes the response of the airplane that is being imitated. This response is then transmitted to the control panel and shown to the pilot. Consequently he can refer to these instruments and fly the airplane just as if he was flying a conventional airborne airplane in actual flight. He is so to speak flying blind by the normal instruments.

Now, while flying the vehicle the pilot has many other inputs that he feels, rather than just the visual ones of his instrument panel. He has the accelerations of the airplane, its rotations, the vibration, the noise. All of these either help or hinder him in the performance of his duties. As an example, I might mention the rocket airplane or booster vehicle such as the X–15, a model of which I have here, or the Dynasoar vehicle that has been discussed earlier. Here you have a very high level of rocket thrust which may put as much as perhaps 8 G. on the pilot during the launch portion of the flight. This level of acceleration is sufficiently high so that it could be expected to interfere with the pilot's ability to control. To adequately simulate this on the ground then requires some modification to our stationary simulator for we can't draw conclusions about the effects of acceleration from the stationary simulator. We should check it under the actual acceleration. The manner that we do this is shown on this chart.

CENTRIFUGE SIMULATION

We use the elements of the cockpit, the instrument panel, and the electronic computer from the stationary simulator and we put the pilot and his cockpit on the end of a centrifuge and whirl the thing around like a stone on the end of a string. This then generates the actual acceleration in which we are interested. To give this the proper direction we can rotate the pilot in this compartment so that the ac-

celeration, which of course is directed outward from the center of the centrifuge, is directed as far as the pilot can tell in the proper sense to simulate the rocket boosting into orbit, for example.

We have performed an investigation in the Naval Air Development Centers' human centrifuge of the boost and reentry portions of the X–15 flight envelope, and, at present, have in progress on the same centrifuge a program to investigate a pilot's capabilities during the multistage boost of the Dynasoar configurations. That is, the X–15 only has one stage of rocket boost and then its fuel is exhausted while Dynasoar may have two or three stages of rocket boost. Thus, we are now investigating by simulation to determine if the pilot can contribute to the control of the vehicle during the actual flight in this booster phase. Should it be possible, and we believe that it is, for the pilot to actually fly the airplane and be responsible for the control during this phase, the reliability of the overall operation should be increased considerably since automatic control is questionable; that is, a failure of such control may lead to the intentional stopping of the launch operation.

CONTROL REGIONS

I would like to proceed then to the next item, which is vehicle controls. This chart indicates control regions as functions of speed and altitude. The chart is divided into two sections by this red line. The lower section we label aerodynamic control. That is the region that the conventional controls are used, such as ailerons and elevators that you see on normal transport airplanes. In this area, these controls, by deflecting, will modify the airloads on the airplane and cause the airplane to move in response to their application. Above this line, however, there is insufficient air to materially affect the airplane by use of conventional controls.

In this region we are using what we call reaction control. One type of such control are small rocket motors. I have one here that is being used or that is similar to those being used on the F–104 airplane. These rocket motors have very low thrust levels. This one is rated at about 200 pounds of thrust. These rocket motors are installed in the nose and others on the wings of the airplane and by using their thrust they whisk the airplane around in order to perform the rotation that is desired by the pilot. We have two programs underway at present at the high-speed flight station on the use of reaction controls in the airplanes shown on the chart. One of them is the X–15 which Mr. Williams will describe later. The other one is the F–104. The actual relationship of performance of these airplanes is more or less as shown by their locations on this chart.

The questions that we ask ourselves with regard to reaction controls and their use are those of how does the pilot feel about using them, does he want the reaction controls to have this type of action or some other type, does he want them just on and off or would he like to be able to modulate their thrust. In addition, we have a question that gets into the next subject here of cockpit controls. In the X–15 the reaction control is utilized on the left-hand side of the cockpit by the left-hand as a separate control. On the right-hand side the pilot has a conventional control for his aerodynamic controls. So we have a question. Would the pilot prefer to combine these two

and have them blended together in one control? If he does, how should they be blended.

As you move from this conventional control area into the reaction control area, questions arise as to whether you want an abrupt changeover from one control to the other, or should the changeover be gradual, or in what manner should they be blended together. This is being investigated using the F–104 as a flying simulator. This type of simulation isn't on the ground, but as regards danger to the pilot it is being investigated short of the actual conditions with a considerable margin of safety.

LANDING APPROACH

The last subject that I would like to discuss in detail is that of landing. Landings have always been a problem and probably always will be. As the pilot brings his airplane close to the ground, he is nearing a pretty solid object that may do him a lot of damage. It may seem odd that hypersonic airplanes, as fast as they are, have landing problems, but it is because of the very nature of the configurations, that is, extremely highly swept wings and the very short span, that introduce problems of extreme rate of descent and high approach angle. In other words, the airplane in its landing approach is coming down extremely steep and at a very high rate of vertical velocity.

These are problems that we are investigating now in flight. To give an idea of what we are talking about here, I have plotted on this chart the approach angle and the vertical speed for various airplanes. There are no points shown on the line because the scale is nonlinear. As you can see, present-day fighter-type airplanes such as the F–102, 104–A, X–1 have approach speeds, that is vertical velocities in the approach, ranging from about 40 miles per hour up to about 80 miles per hour, and in general have fairly low approach angles.

The hypersonic vehicles that we are discussing today such as the X–15 and these two that are somewhat of orbital type, have much steeper approach angles, and have vertical velocities in the landing approach that may get as high as 200 miles an hour. In order to investigate these characteristics we used an F–104 airplane and increased the drag sufficiently to move it out into this general area, so that it is again simulating flight of the X–15 or these orbital vehicles. We then performed landings in these conditions. It was found possible to land with vertical velocities in the approach as high as 200 miles per hour. However, the pilots felt this was about the limit for this configuration, and that it was not the sort of a thing that a pilot could be sure of doing on his first attempt; that is, it would require additional practice.

In order to give you an impression of the extremity of such a maneuver, I will quote a few numbers with which you may be familiar. The conventional transport airplane descends from an altitude of about 18,000 feet. The descent time will be about 30 minutes to the time it starts its landing approach. For an airplane such as the F–102 or the F–104, operating in service, from 18,000 feet to a landing will require about 5 minutes. For the F–104 operating in this simulated condition, the approach and landing from 18,000 feet is accomplished in seconds. To the observer it appeared to be a controlled

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crash. One expected to see the airplane go through the runway when it contacted. We are continuing the investigation in this area to determine the factors that affect the landing; in other words, to learn how to best use the pilot's ability. For example, he might be able to land at a higher angle if his wing loading was reduced, or if the airplane configuration was changed.

OTHER PILOTING AND CONTROL PROBLEMS

Before closing, I might mention briefly these other four items.

Stability—as Mr. Becker mentioned, is a considerable problem because of the extremely wide ranges of speed of these airplanes. The problem of stability appears to be relatively easier to solve for blunt shapes than it would be for extremely long, thin ones.

Automatic control—I have mentioned before in relation to the role of the pilot.

Navigation and guidance—these are terms which are used to describe the general problem area of answering the question that the pilot has with regard to, "Where am I, where am I going, and how do I get there?" We are doing a considerable amount of work in that field, particularly since the boost-glide vehicle, as Mr. Becker described, goes a tremendous distance after the power is off. The pilot has to navigate it; even though he cannot turn around and come back, he can appreciably deviate from the path established when the boost power goes off.

Environment—I feel I have discussed that sufficiently in talking about the centrifuge.

PILOTING AND CONTROL OF MANNED HYPERSONIC VEHICLES

PILOTING AND CONTROL PROBLEM AREAS

ROLE OF THE PILOT

SIMULATION AND TRAINING

VEHICLE CONTROLS

COCKPIT CONTROLS AND DISPLAY

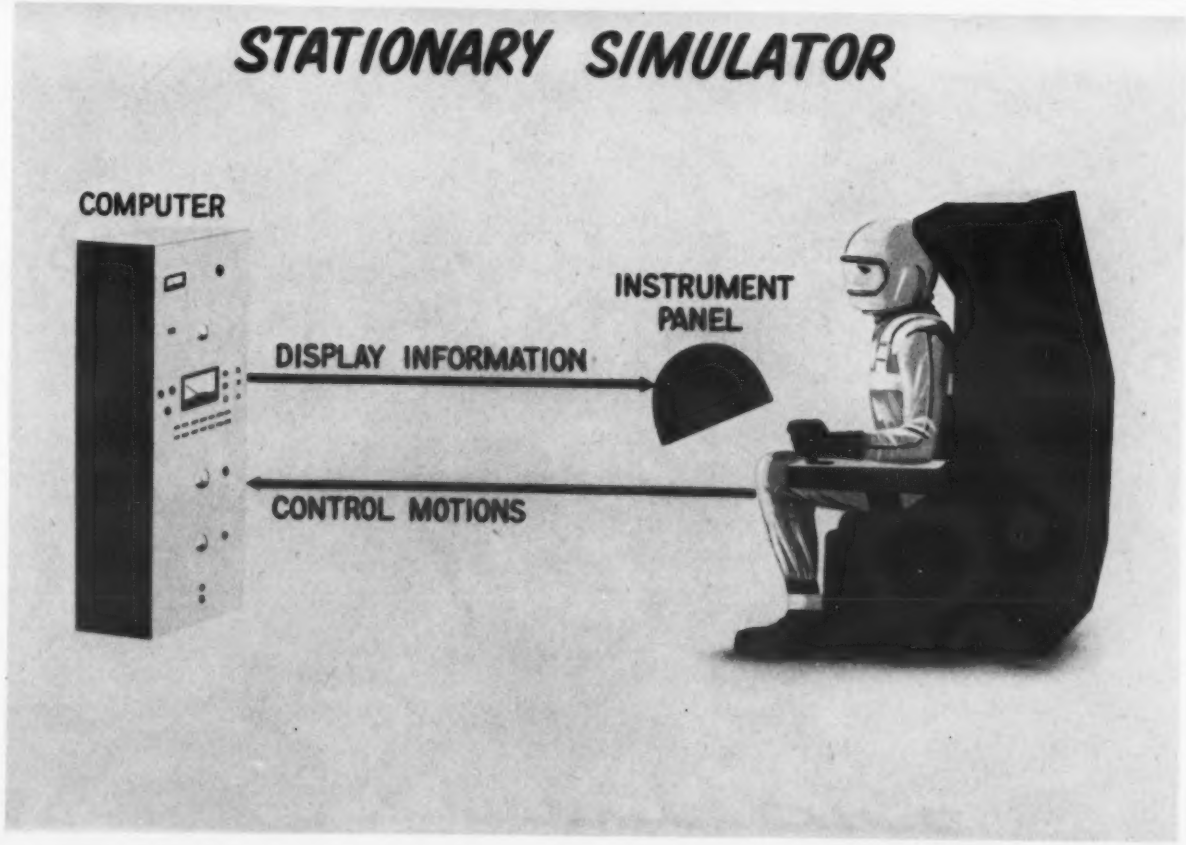
LANDING

STABILITY

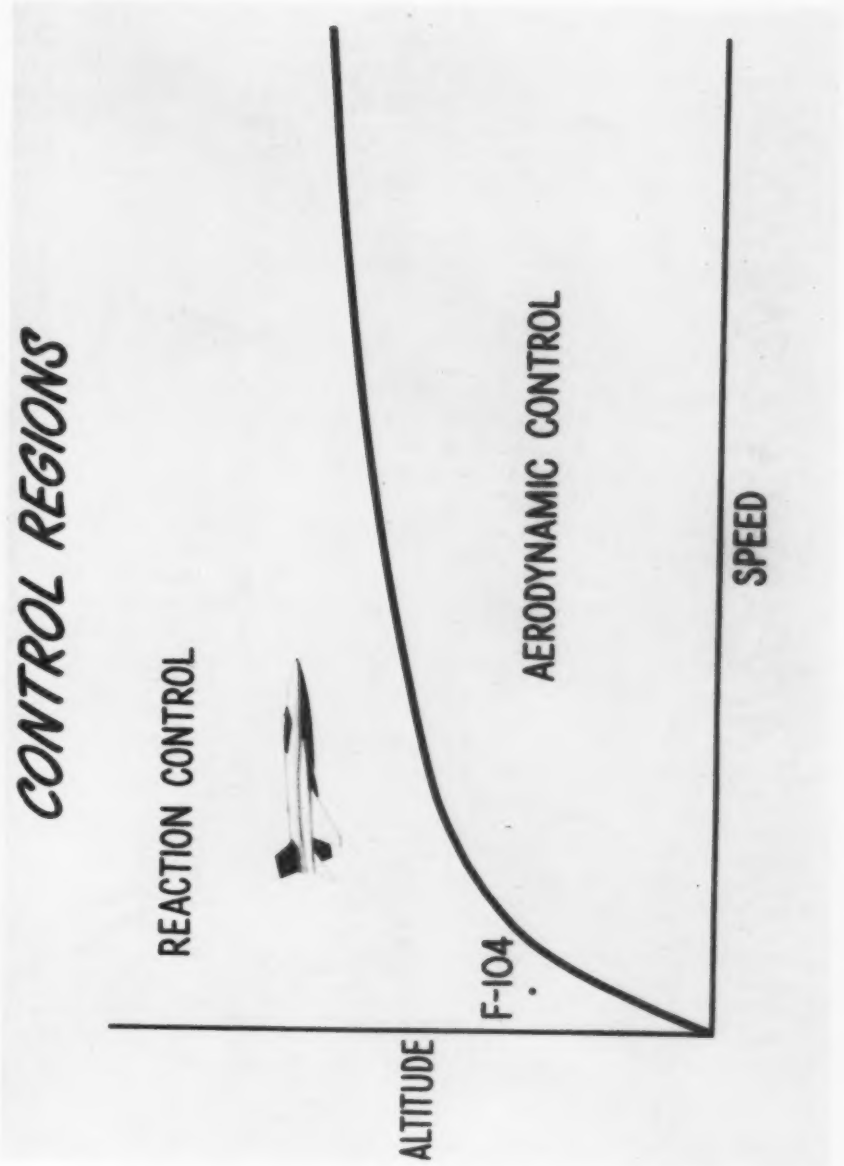
AUTOMATIC CONTROL

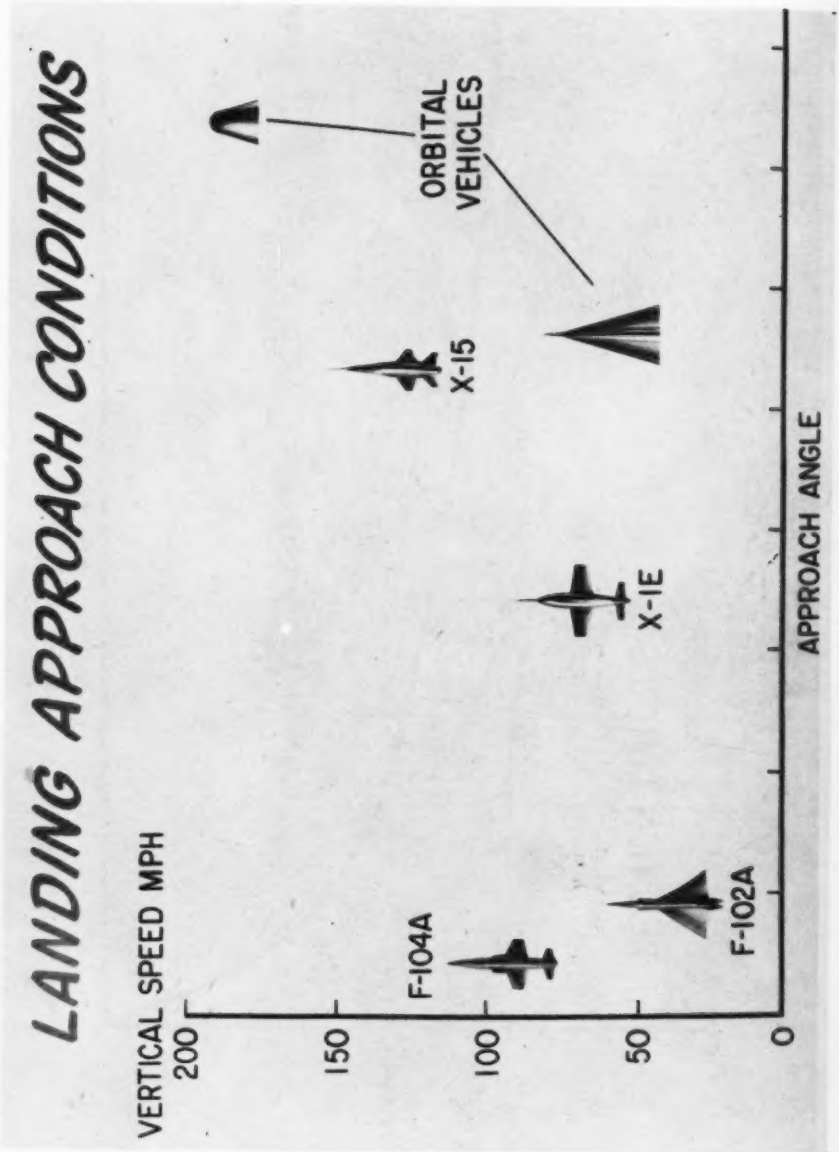
NAVIGATION AND GUIDANCE

ENVIRONMENT


STATIONARY SIMULATOR
COMPUTER
INSTRUMENT PANEL
DISPLAY INFORMATION
CONTROL MOTIONS

SIMULATION BY CENTRIFUGE


CONTROL REGIONS
REACTION CONTROL
AERODYNAMIC CONTROL
F-104
ALTITUDE
SPEED


LANDING APPROACH CONDITIONS
VERTICAL SPEED MPH
200
150
100
50
0
F-104A
F-102A
X-1E
X-15
ORBITAL VEHICLES
APPROACH ANGLE

Senator STENNIS. We will depart here a little from our presentation—Senator Cannon is an experienced pilot and a current jet pilot. I think you could help the committee and the record, too, Senator, if you would ask any questions here of Mr. Drake that you may have in mind.

Senator CANNON. I might state, Mr. Chairman, that this is a little out of my field—the figures they are talking about—but I can certainly appreciate the problem when you are talking about vertical landing speed of 200 miles an hour or thereabouts, because to me it almost sounds like an uncontrolled crash landing instead of a controlled crash landing.

Senator STENNIS. Well, any comment you could make along that line, or any other point, I think would be helpful for the record here, Senator Cannon.

ADDITIONAL CONSIDERATIONS RELATED TO X–15 RESEARCH AIRPLANE

Senator CANNON. I was interested, Mr. Drake, in hearing your reference to the X–15. Just a short time ago I sat in it and was given a cockpit check on it by Crossfield, the test pilot who will probably be the first to fly in it. I was noticing the fact that you are having to develop a new theory of control, since man himself has not been able to have the movement of his body due to the excessive or high G forces—therefore the controls will be operated by a movement of his hand, wrist, either forward or back, or by the rotation of his wrist.

Is that problem going to last throughout these orbital flights in your opinion?

Mr. DRAKE. This type of control will undoubtedly be used in these orbital vehicles. During the long glide they will not encounter the high decelerations that the X–15 will. However, during the launch, high accelerations during boost will be encountered. We don't feel that the moving of the control from the conventional center position to the side and the use of such control for the airplane will introduce too much of a problem. We have currently a flight control simulator out at Edwards in the F–107–A airplane where we have such a control and we are flying this airplane in order to gain experience with this type control before the X–15 has made its flights. This has been flying now for several months.

Senator CANNON. You say the pilot will not go through the deceleration processes as in the X–15?

Mr. DRAKE. That is right.

Senator CANNON. In your Dynasoar?

Mr. DRAKE. The deceleration in the Dynasoar will always be less than 1 G.

Senator CANNON. It will be?

Mr. DRAKE. Yes. The X–15, however, is capable of ballistic flights. Well, I should qualify that. The design trajectory of the Dynasoar, that is for long range, is at very low G. It is capable of a certain amount of ballistic flight, however, and thus it will encounter decelerations above 1 G.

Senator CANNON. In other words, the thing I was thinking about was the reentry problem. If you have got an orbital vehicle, wouldn't you encounter the same deceleration problems at the time of re-

entry into our atmosphere, whether it is orbital, X–15, or whatever it is?

Mr. DRAKE. It depends upon the entry angle at which the entry is being made. The X–15, in order to get out of the atmosphere, does it very steeply and comes in very steeply, and the Dynasoar will be coming in essentially tangentially into the atmosphere.

Senator CANNON. So, if you can reduce the rate of reentry into the atmosphere, then you won't have the high G or deceleration forces that the X–15 will encounter?

Mr. DRAKE. That is right.

Senator CANNON. Does that let up on your problems of your reentry metals?

Mr. DRAKE. No; the flatter angles are more demanding of reentry structure.

Senator CANNON. You have more heat generated on those?

Mr. DRAKE. Well, you are in the high-heating region a much longer period of time.

Senator CANNON. What is the plan now of the first free flight on the X–15?

Mr. RHODE. If I may interrupt at this point, our next speaker is Mr. Walter Williams, head of the NASA High-Speed Flight Station, who will tell you about the X–15, and he is up to date on all that information.

Senator STENNIS. All right.

Senator Martin, did you have something at this stage, or do you want to wait for the next one?

Senator MARTIN. I don't have very many questions.

I am interested in the description you made of the X–15 coming so straight down—do you have the idea of quickly reducing the number of G's through maneuver of that plane?

Mr. DRAKE. I think Mr. Williams will go into this in some detail.

Senator MARTIN. I think that is the only question I have right now.

Senator STENNIS. All right. The next witness, please.

Mr. RHODE. Mr. Chairman, before I call on our next speaker, I should like to say that at one of the previous hearings of the NASA before the Space Committee of the Senate, an interest was expressed on the part of some of the members in obtaining models of the X–15 airplane such as Mr. Drake has displayed this morning in his discussion.

I am happy to be able to say now that steps have been taken to provide the members of the committee with models of the X–15 airplane.

Senator STENNIS. That is very fine.

Senator CANNON. May I offer a comment? I would suggest to the members that they be careful about them because apparently they are very fragile. So treat them with care.

Senator STENNIS. We certainly will. You are not going to break this nose cone that has been passed around here.

All right, who do you have next?

Mr. RHODE. Mr. Chairman, our next speaker is Mr. Walter C. Williams, Chief of the NASA High-Speed Flight Station at Edwards, Calif. He will tell you about the X–15 research airplane.

Senator STENNIS. Come around, Mr. Williams. We are glad to have you here, sir.

TESTIMONY OF WALTER C. WILLIAMS, CHIEF, NASA HIGH-SPEED FLIGHT STATION, EDWARDS, CALIF.

Mr. WILLIAMS. Senator Stennis, I would like to talk now about a flight project where we take our laboratory lessons and integrate them into a flying machine; one, to see if the lessons we learned were correct, and two, to see if there is anything that we overlooked in our laboratory work. Occasionally we do have some surprises in this business.

Now, the X–15 is the latest of our research airplanes. The first, as you probably know, was the X–1 which gave us our first supersonic flight. The X–15 will be the first one to take us to the fringes of space, so to speak.

INITIATION OF X–15 PROJECT

Now, the milestones in the development of the program are these: The airplane became an identifiable item in the NASA research programs as early as 1952 when we initiated studies of problems to be encountered in space flight. These studies were culminated in 1954 with a firm proposal for a research airplane.

This was presented to the Air Force and Navy, and an agreement was reached for a joint endeavor. In fact, a formal memorandum of understanding was drawn up where the National Advisory Committee for Aeronautics had technical direction of the program, the Air Force would administer the design and construction phases, and the NACA had the responsibility for the flight tests.

North American, after a design competition, was given a contract to go ahead with three airplanes in December of 1955. In October of 1958, the first X–15 airplane was rolled out and delivered for flight tests. Since then there have been numerous ground tests of all the various accessories and power systems within the airplane.

INITIAL FLIGHTS OF X–15

Two complete captive flights have been made, and perhaps I should explain what I mean by this. The X–15 airplane is carried aloft under the wings of a B–52; the plane is taken to high altitude and then released to make its research flight.

This device also gave us a very rare opportunity that the X–15 airplane's first flights, in a sense, can be made without releasing it, and we can then exercise the systems within the airplane without running the hazard of having the free flight.

Two such flights have been made. There have been some minor difficulties with systems. Actually a third such captive flight is underway right now. In fact, we have been airborne roughly 30 minutes. They took off at 11:22 Washington time this morning. So far as we know, things are proceeding satisfactorily.

Senator STENNIS. From where?

Mr. WILLIAMS. From Edwards Air Force Base. It was 8:22 California time. The plan is to have a successful functioning of all systems prior to planning the flight with the airplane released. Now, after completion of a successful captive flight, I would expect it would be roughly a week's time before the airplane would be turned

loose into a glide flight. The first free flight will be glide flight only, and this will be followed by a power flight with rocket propellants aboard.

Now, I think most of you are generally familiar with the appearance of the X–15, since it has appeared in a number of the newspapers. It is in a sense relatively conventional in appearance. It doesn't look unlike a Century series jet fighter. Its difference really lies in the manner in which it is constructed, and the internal arrangements. The skins, as you know, are of Inconel X, which is a nickel alloy rather than the usual aluminum alloy with which we have been building airplanes.

X–15 INTERNAL ARRANGEMENT

The internal arrangement actually approaches that somewhat of an ICBM missile. The major portion of the fuselage is taken up by the fuel tank in red on the chart, and the liquid oxygen in green, and the associated equipment running back to the rocket engine.

Following the chart, of course, here is the cockpit, equipment and ejection stick, and the three control sticks mentioned in the earlier talks. A large area is taken up by instrumentation. Really, in a sense the heart of the airplane is the compartment which holds the small turbine units that drive generators and hydraulic pumps that supply electrical energy for the airplane systems, as well as the hydraulic power required to operate the control surfaces.

Also the small yellow spots on both wings and the nose are locations of the space controls or reaction rockets that Mr. Drake talked about.

The landing gear of the airplane is somewhat unusual. It has a conventional nose gear shown in the retracted position, and then the main gear, which, rather than being wheels are skids that extend from the rear of the fuselage. On the black model it is very difficult to see them, but they are shown here laying against the side of the fuselage. They come out like bird's legs, which is about the best way to describe them.

The fuel tanks actually are integral tanks which are also part of the fuselage structure. The airplane is all one piece, so to speak.

X–15 PERFORMANCE

Now, as far as performance and what we can do with the X–15, I have a plot of altitude and speed. The maximum speed of the airplane is in the general area above 3,600 miles an hour, depending on the exact altitude. The airplane is still increasing its speed when the rocket propellants are exhausted.

Of course, you can trade speed for altitude. Essentially what I mean is there is a maximum altitude which can be reached from where a satisfactory recovery is feasible. Higher altitudes than this are within the performance capability of the airplane. However, we do not know at this time whether it would have sufficient control to recover from such a higher altitude.

Part of the flight envelope is available to us in terms of space flight where aerodynamic forces would be negligible. We will be faced with aerodynamic problems in another part of the flight envelope. In the space area we will be able to work our reaction con-

trols. The pilot will be subjected to weightlessness and be in what you might call a space equivalent condition.

To give an indication of the performance increase that the airplane represents, I would like to draw your attention to the point that the lower speeds have been well explored by our military jet fighters. Next, the envelope covered by the X–2 airplane's speeds is somewhat in excess of 2,200 miles an hour and altitudes on the order of 26 miles.

TYPICAL X–15 FLIGHT

With this performance in mind, we might have a look at what a typical mission might be. The airplane will be operated over an instrumented radar telemetering range extending essentially from Wendover, Utah, to Edwards Air Force Base. We have stations at Ely, Nev., and Beatty, Nev. We selected this particular route because there are numerous dry lakes in the route which would provide for emergency landing in the event of an emergency.

Senator STENNIS. Dry lakes, you say?

Mr. WILLIAMS. Yes, sir. Edwards, of course, has a very large dry lake and this is our prime reason for conducting the operations at that point. It has been dry for a number of years now. In addition, there are lakes disclosed along this route that will cover just about every emergency that we have thought of, anyway.

Now, at Wendover there are the Bonneville Salt Flats, and these will provide a good emergency area if for some reason after launch the rocket engine does not start.

I have a detailed item here that perhaps Senator Cannon would be interested in. In the rocket system we will do everything prior to launch but actually open the main propellent valves. The turbine pump will be operating; in fact, the igniter will be on, so we are trying to have as many as possible of these processes take place prior to launching the airplane. This will reduce the possibility of having an abort flight and an emergency landing.

This particular mission is called an altitude mission, where the objective is high altitude rather than necessarily the higher speed on the airplane. Of course, as other people have mentioned during this period, the pilot will undergo high longitudinal accelerations forcing him back in his seat, and this will increase from the time he fires his rocket engine. As the airplane lightens, it will go up to the order of 5 G's.

Now at that point he will run out of fuel. However, he will coast upward to a higher altitude and it is in this area that he will experience a weightless condition and will work the space controls or rocket controls to properly orient the airplane in order to make his reentry.

The reentry essentially would begin to cause the airplane to heat up, and the pilot will have to exercise very precise control in order to avoid overheating or overstressing the airplane.

At the completion of his reentry he will be about 80,000 feet and perhaps 3,000 miles an hour, and his problem then is to navigate to Edwards and land the airplane.

Senator STENNIS. No power left there?

Mr. WILLIAMS. It is a glide-out. In fact, from this point on it is a glide-out. He will have radar monitoring all along the flight path.

At present North American is engaged in a demonstration of the airplane. This stage of the game is essentially their responsibility to show us they have a machine with systems that are functioning properly; that the structure is sound within known flight regions, up to speeds of the order of 2,000 miles an hour and altitudes of perhaps 20 miles.

FLIGHT RESEARCH PLANS

When this demonstration is completed, then the Government agencies will take over. This is the NASA High-Speed Flight Station and the Air Force Flight Test Center. We will then conduct an exploratory flight program to reach the designed missions of this airplane. The airplane will actually be flown by Air Force and Navy pilots and NASA pilots. We will do the program in a step-by-step manner, not necessarily in given increments of speed but in increments of knowledge.

We will also try to extrapolate our experience in the next advance. I don't want to imply by that we know very little about the airplane, because we know a lot. Yet we don't know enough in one flight to go out to the maximum performance.

There has been a lot of work on the X–15. There has been over 4,000 hours of wind tunnel testing, and this is actually many more hours than the airplane will ever fly.

We have made simulator studies, and pilots have flown the profile of the X–15 airplane in a very satisfactory manner in the Navy centrifuge. We have been able to do things like map the heating expected on the airplane, quoting temperatures up to 1,200°, which is the safe working range for the Inconel X.

On the model here the colors are in descending order of temperatures. The dark colors here are below 800° F. The red is 800 to 1,000; the orange, 1,000 to 1,100, and the yellow, 1,100 to 1,200. As

previous speakers have shown the areas at the nose and wing leading edges are exposed directly to the wind as you fly and get very hot. There is also a pullup reentry case, where certain parts are cooler on the back side or shadow areas of the structure than are the exposed areas.

This information is good enough for design purposes when we design a safety margin in the airplane, but because we do not know the actual flow conditions in free flight and the exact manner in which the heat will be transferred to the structure we have certain areas of uncertainty.

On this chart we have structural temperature plotted against speed. With a predicted temperature line. But at any given speed we have an area of uncertainty which could be off as much as 400°. If this part is a critical structural component, we must approach our flight testing in such a manner to narrow this band of uncertainty down as our speeds increase. In this manner we get the maximum utilization of the airplane without exceeding its limits.

DISTRIBUTION OF FLIGHT-RESEARCH RESULTS

I would like now to mention a little of the manner in which our research information has been distributed.

One of our commitments on the X–15 agreement is to make the flight results available to the industry and the services. We will do this in the usual NASA reporting manner, and in the large conferences we arrange for industry and the services. We have had two large conferences so far. We found on our previous research airplanes that some of the lessons learned during construction of the airplane are of the same importance as the actual flight tests. We expect to have a third conference when we reach the design performance of the airplane. We think that at that time we will be able to give a good assessment of the role that man can play in space flight, since he is in complete functional command throughout the flight.

X-15 RESEARCH AIRPLANE PROJECT

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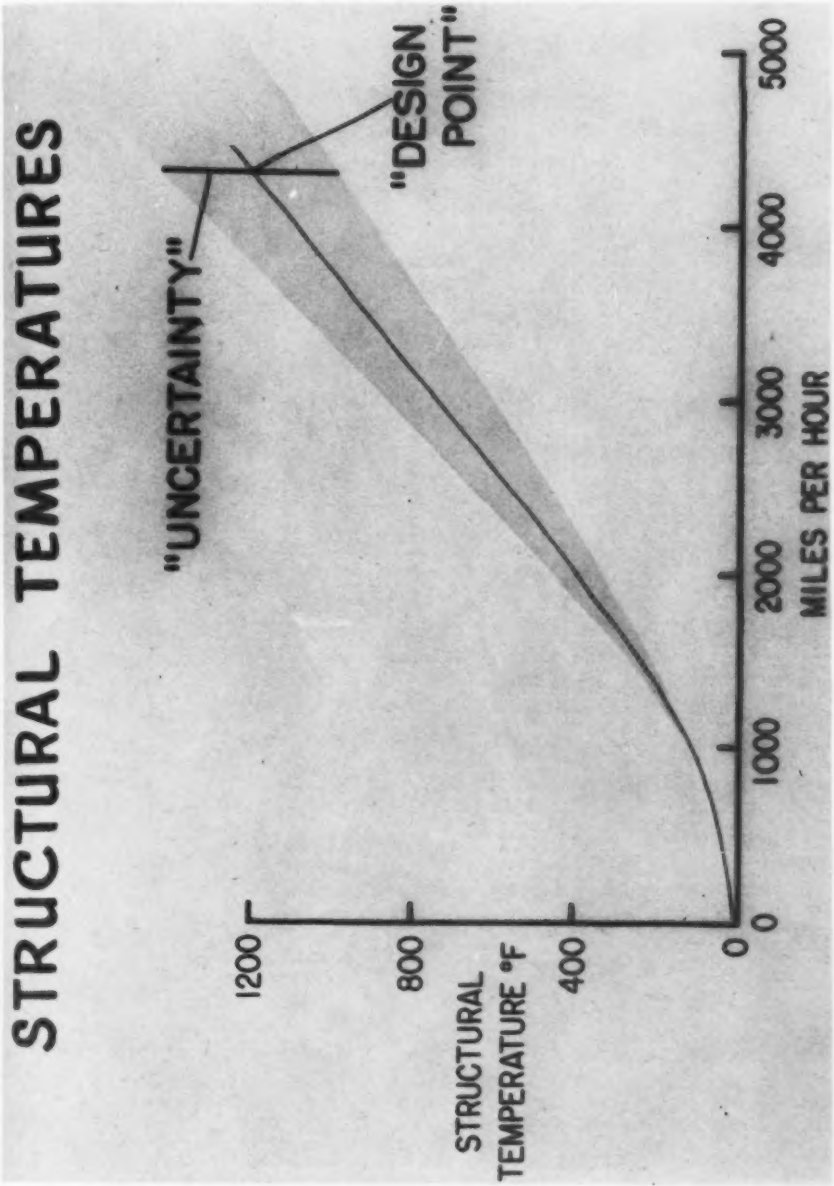
APRIL 1952	NACA INITIATES STUDIES OF SPACE FLIGHT PROBLEMS.
JULY 1954	NACA COMPLETES STUDIES AND PRESENTS X-15 PROPOSAL TO AIR FORCE AND NAVY.
DEC. 1955	NORTH AMERICAN AVIATION GIVEN "GO AHEAD" FOR THREE X-15'S.
OCT. 1958	ROLLOUT AND DELIVERY TO FLIGHT TEST.

X 15 TYPICAL MISSION
ALTITUDE - 100 MILES
VELOCITY, 3600 MILES PER HOUR
WENDOVER
ELY
BEATTY
EDWARDS

X-15 AERODYNAMIC HEATING
1100°F TO 1200°F
1000°F TO 1100°F
800°F TO 1000°F
BELOW 800°F


STRUCTURAL TEMPERATURES
"UNCERTAINTY"
"DESIGN POINT"
1200
800
400
0
STRUCTURAL TEMPERATURE °F
0
1000
2000
3000
4000
5000
MILES PER HOUR

Senator STENNIS. I assume that this is a natural breaking point for questions.

Mr. RHODE. Yes, it is. We are at your pleasure, sir.

Senator STENNIS. May we have a few questions? Mr. Williams, will you go back there to your chart on the internal arrangement?

Mr. WILLIAMS. Yes, sir.

Senator STENNIS. I think since you have shown the X–15 there and the model flight, if you would briefly summarize what you said on internal arrangement I believe it would have added significance. It would to me.

Mr. WILLIAMS. Suppose I start on the nose and go back. Actually if you notice, rather than the sharp needle noses of the previous high-speed airplanes, this one actually has a hemispherical nose. It is a ball about 6 inches in diameter.

The first items of interest are the rocket controls, and these are the ones that will pitch the airplane and yaw the airplane in space flight.

The next compartment is actually the landing gear or nose gear compartment, and the gear is shown in the retracted position.

Next is the cockpit. The cockpit is pressurized. It has a stabilized ejection seat that has been proven in tests on the high-speed track at Edwards. The pilot also wears a full pressure suit which was especially developed for this program. It also will be essentially the suit worn by the Mercury astronauts.

X–15 PRESSURE SUIT

Senator CANNON. Mr. Williams, will you tell us a little about that suit?

Mr. WILLIAMS. Yes, sir. It provides protection against accelerations, it is a G suit. It provides protection against loss of pressure, and it is also a ventilating garment. Cool air is circulated through it continuously. In the event there was loss of cabin pressure, the rate of exhaust of this cooling air is decreased and the pilot is in turn then pressurized. It provides atmosphere and environment completely to the pilot himself, independent of what is going on within the airplane.

Senator CANNON. In other words, if his cabin would pop open, he is completely protected at high altitude—the suit has a helmet on it fastened directly to the suit, and the glass comes around his face and the helmet is air conditioned, is that right?

Mr. WILLIAMS. That is correct. In addition, in the event of a high-speed ejection, the suit will provide protection to the pilots. The suit on a dummy has run down the track at Edwards at speeds up to about 1,600 miles an hour, which at sea level are very high forces on the dummy. The suit was able to stay together, so this will provide protection in the event of ejection as well.

Senator SMITH. How much would that suit weigh?

Mr. WILLIAMS. About 30 pounds.

Senator SMITH. What is it made of?

Mr. WILLIAMS. It is a multilayer suit which has been devised to give proper pressure retention and yet allow good mobility. Since the details of the internal mechanisms of the suit are classified, the pictures show only the external silvered flying suit with boots, gloves, and the large domed helmet.

Senator SMITH. It is made of cotton and wool rather than nylon or Dacron?

Mr. WILLIAMS. There may be some nylon in one of the synthetics in one of the outer garments.

Senator CANNON. There are synthetics.

Senator STENNIS. All right, proceed; I meant for you to summarize; just go back there to the capsule.

Mr. WILLIAMS. I think we have covered the cockpit now.

Senator STENNIS. Yes.

FUNCTIONS OF FUSELAGE COMPARTMENTS

The next compartment is the instrumentation compartment, and here are essentially the recorders. Now, there are sensors distributed all through the airplane, and the intelligence is piped or wired into the recorder here and recorded on the film.

The next section is called the accessory section, or APU section. I believe APU is noted on the model there. That is the exhaust from the peroxide turbines; hydrogen peroxide is decomposed into steam, drives these small turbines, which in turn drive the generators and the hydraulic pumps for the airplane. They are located in that behind the canopy. This has been one of the troublesome items during the captive flights. However, it is so essential to the success of of the flight that we want to be very sure the APU's are working very well before we ever turn the X–15 loose. The reason we have two is if one fails we have another to back it up. However, if both fail, the pilot will have to eject.

The next section of the fuselage is taken up by the liquid oxygen tank, with its piping back to the rocket engine. The fuel tank with its associated piping follows.

Senator STENNIS. You say the fuel tank and the liquid oxygen tank—what kind of fuel is shown in red?

Mr. WILLIAMS. This will be ammonia as fuel.

You may notice a number of small balls essentially. These are high-pressure spheres, a spherical container holding high-pressure gas, helium in some cases, nitrogen in others, and these are used to pressurize the tanks to force the liquids through the pump and purge the rocket cylinder of any extraneous fuel prior to firing. Essentially these are small arrangement sources to make the rocket work.

LANDING FACTORS

Senator CANNON. Will you explain what else happens back here on landing?

Mr. WILLIAMS. Yes. This is very interesting.

We drop part of this airplane when we land. When the skids come down, they do not extend far enough to clear this vertical fin, so the fin separates at a point here, and is dropped off. It is fired off by a charge prior to landing. I think you can see the separating line on the model here.

Senator MARTIN. Is that the separation point?

Mr. WILLIAMS. Yes; right here.

Senator MARTIN. And the fins come out further?

Mr. WILLIAMS. This is the complete fin as the airplane will be flown. Before landing this portion below this line drops off. These are the landing skids.

Senator MARTIN. And the skids come off?

Mr. WILLIAMS. They extend.

Senator STENNIS. Is it correct that this is just an experimental vehicle?

Mr. WILLIAMS. Yes, sir.

Senator STENNIS. And it doesn't have a goal of carrying within itself a payload eventually. This is preliminary to others that will have a payload?

Mr. WILLIAMS. No, sir; that is correct. This airplane's payload is right in this compartment, the instrumentation and the pilot.

Senator CANNON. As a matter of fact, you get a very limited number of flights out of the aircraft at full capacity because of the metal fatigue.

Mr. WILLIAMS. I don't think this is a problem we know enough about at this time for me to make a firm answer. It is something we are concerned about, and we have to watch ourselves.

Mr. RHODE. I think I might speak to that one briefly, Mr. Chairman. I doubt very much whether metal fatigue will be a very serious limitation on the X–15 airplane.

Senator STENNIS. All right.

Senator Smith, do you have some questions?

Senator SMITH. No questions.

Senator STENNIS. Senator Cannon, do you have any further questions?

Senator CANNON. No.

Senator STENNIS. Senator Martin?

Senator MARTIN. I believe you answered this in the graph you had a moment ago showing the flight leveling off—the question I had in mind was about landing speed being brought down within control.

Mr. WILLIAMS. Yes, this airplane will land at about 160 knots, or 180 miles an hour.

Senator CANNON. Just one further question:

What speed is the aircraft, the X–15—I mean, what altitude does it drop from the B–52?

Mr. WILLIAMS. We are planning at this time to drop at 38,000 feet at Mach number of about 0.8.

Senator CANNON. When he starts to reenter, is he going to attempt to try to raise his nose, that is, to skip in?

Mr. WILLIAMS. No, it will be a relatively steep reentry. Actually there are a number of ways we can do it. One is to come in at constant angle of attack, so once he establishes his angle the airplane will make a pullout as the air gets thick.

Senator CANNON. Approximately what speed do you anticipate he will glide from after he has reentered the atmosphere until he is down to where he can make his landing pattern?

Mr. WILLIAMS. At the reentry point where he has leveled out, he will still be doing between 2,000 and 3,000 miles an hour, and then he will be continually killing off speed and losing altitude until he arrives over Edwards, and we would like to bring him over the station at, say, 40,000 feet.

Senator CANNON. At 40,000 feet, what speed do you anticipate he will be at then?

Mr. WILLIAMS. He will be subsonic, 400 or 500.

Senator CANNON. 400 or 500?

Mr. WILLIAMS. Yes.

Senator STENNIS. It seems to the Chair that we are coming to a place for a recess, because we go into a new group of witnesses. We can give Mr. Williams and Mr. Rhode a chance now to say anything further and we will get out at 12:30. We will come back at 2:15, and have about 2 hours of very good presentations this afternoon, and that will close the technical side.

Mr. Rhode, did you have something further to say now before we take this recess?

Mr. RHODE. Not at this point, sir.

Senator STENNIS. I mean any added point about what we have covered this morning?

Mr. RHODE. No, sir, I think not.

X–15 POWERPLANT

Senator STENNIS. Mr. Williams, Mr. Lehrer has suggested that maybe during these few minutes you could go back and give us a little bit more on the engine parts, your power units there. It is more interesting to me going over it the second time. Would you like to point out a little further information about the power unit?

Mr. WILLIAMS. All right, sir.

This is a rocket engine, contrasted to a tubojet.

Senator STENNIS. Yes.

Mr. WILLIAMS. This means we carry both our oxidizer, since we are not using air, it is not an air-breathing instrument, we are carrying our own oxidizer and we need fuel with it to burn. It is a single-rocket chamber. In order to put the fuel in the chamber at the proper pressures, it is forced in by a pump. This pump again is turbine driven, and driven by hydrogen peroxide which is decomposed, and essentially the product then is steam. This will force the propellants into the rocket, and of course they are ignited there by essentially a smaller rocket which was started in the first place by a spark plug.

Senator STENNIS. What about this engine now? Do you already have it available?

Mr. WILLIAMS. No, sir, the large engine, that is our final engine, will begin its preliminary flight rating tests at the reaction motors plants about the middle of this month, I don't recall the exact date.

Senator STENNIS. When did you say you expected it to be available?

Mr. WILLIAMS. The schedule—it is scheduled for availability at Edwards in August.

Senator STENNIS. That is a very short time.

Mr. WILLIAMS. Well, it has been under development for a long time. These are the flight rating tests that are being conducted now which require that essentially the engine be operating satisfactorily for an hour's running time, not continuously, but an hour's running time.

At this time we are using two of the rocket motors that have been successfully used in our earlier airplanes such as the X–1, the D558–2

Sky Rocket. This will give us a performance potential up in excess of that about 40 or 50 percent better than the X–2, mach numbers close to 4. So even with these small engines we will be able to get started, we will get started on our program even though the large engine is not on the site at this instant. And actually, it makes for an easier flight test problem since with the large engine, which is throttled there is a limit to the amount of throttling you can do on a rocket engine and have efficient running.

So we are throttling down ——— thrust, and even with this thrust the airplane will go very fast, and it would be difficult to break our speed down into finite increments below 2,500 to 2,800 miles an hour. We are using two old engines, each have four cylinders, so in this way we have throttling by eighths, so to speak, on the thrust, and will make it a reasonable way to build up the speed of the airplane at least up to the point where we need the large engine to take over. As a matter of interest, this means enough to us that we plan that every pilot who we expect will fly the airplane with the large engine, will fly it with the small ones, to give him a good chance to become familiar with it.

Senator STENNIS. In the meantime, do you plan these glider runs in the interim?

Mr. WILLIAMS. Yes; there probably will be only one glide flight.

Senator STENNIS. Only one?

Mr. WILLIAMS. Yes, and then we will go into the pilot program with the smaller rocket engines.

Senator STENNIS. How many pilots have been trained to handle this X–15?

PILOTS BEING CONSIDERED FOR X–15 FLIGHT

Mr. WILLIAMS. There are essentially eight pilots in the program that we are considering for flying the airplane; two of these are North American pilots, one is the backup. Of course, I think you have all heard of Scott Crossfield, he formerly was with us before he went to North American. He has a backup pilot. Then there are three of our test pilots, Mr. Walker, Mr. McKay, and Mr. Armstrong, Captain White and Captain Rushworth of the Air Force, and Lieutenant Peterson of the Navy. All of these people might be classified as experienced professional test pilots. This is the next step down the line for them. I think five of them have flown the earlier rocket airplanes. All of them have flown high-performance jet airplanes in tests, so this is a logical progression for them.

Senator STENNIS. In the guideline you gave in the beginning of the talk here, Mr. Rhode, you used this word "hypersonic." You said that meant 1 mile per second or more.

Mr. RHODE. That is correct, sir.

Senator STENNIS. Is that term generally used in this business?

Mr. RHODE. Yes, sir.

Senator STENNIS. All right. Well, that was helpful to me. Are there any other questions now? If not, we will take a recess by agreement until 2:15.

Thank you very much.

(Whereupon, at 12:30 p.m., the subcommittee recessed, to reconvene at 2:15 p.m., this same day.)

AFTERNOON SESSION

Senator STENNIS. The subcommittee will come to order.

Mr. Rhode, we are glad to proceed further now. You are going to be in charge of the presentation on missiles and you may proceed in your own way, sir.

Mr. RHODE. Thank you, Mr. Chairman. Before we proceed with our next presentation, I might just let you know, as a sequel to the piece of news that Mr. Williams gave you this morning relative to the flight of the X–15, that we have since learned that it completed its flight successfully and landed at 12:40 p.m., Washington time at Edwards, of course.

The flight was not what we would regard as entirely successful but it was the most successful of the three flights that have been made to date. There was one minor little item of difficulty that occurred in the auxiliary power system, but this can be readily straightened out.

Senator STENNIS. That is a very encouraging report. I saw General White, Chief of Staff of the Air Force, at noon and I wasn't giving him any news when I mentioned the X–15 being in this third test—he is very much interested. All right, sir.

Mr. RHODE. The next presentation we have, Mr. Chairman, will be given by Mr. Milton B. Ames, Jr., the Chief of the Aerodynamics and Flight Mechanics Research Division of NASA Headquarters. He is going to talk about some missile problems and their solutions. Mr. Ames' paper will be a rather general discussion of the overall picture, and the subsequent speakers will develop in somewhat more detail certain of the problems that Mr. Ames will mention.

Senator STENNIS. Mr. Ames, we are glad to have you, sir. Will you proceed?

TESTIMONY OF MILTON B. AMES, JR., CHIEF, AERODYNAMICS AND FLIGHT MECHANICS RESEARCH DIVISION, NASA

Mr. AMES. Thank you, sir. The purposes of my discussion are twofold. First, I would like to indicate the areas in which the major problems are experienced in the design and development of the various kinds of missiles. Secondly, I would like to discuss briefly a few examples of the way in which NASA contributes to the solutions of some of these problems. The major missile problem areas, technological areas I want to refer to are given on my first chart. In the area of engine performance, modern missiles require rocket engines which will give the highest possible performance for each pound of fuel and engine weight.

As an example of some of the difficulties here, modern ballistic missile powerplants consume 100 gallons of fuel per second.

The second item is the area of control and guidance. Modern missiles require fully automatic control systems, and these control systems receive their instructions or signals from elaborate electronic guidance equipment. When we couple these parts of the weapons system with the rest of the vehicle, we end up with a complicated array of devices which are required to perform with extreme precision.

By structural efficiency and integrity, I mean that the missile requires the lowest possible structural weight which will withstand the loads, the temperatures, and the vibrations which the missile will experience without structural failure.

The last two areas here, aerodynamic heating and materials, are related and they in turn relate back to our requirement to have the lowest possible structural weight.

In the area of aerodynamic heating we are searching for means by which we may reduce the heat input into the missile. And in the area of materials, we are striving to find better materials and better methods for withstanding the temperatures which will be encountered by the missile.

NASA CONTRIBUTIONS

On my next chart I have indicated the two primary ways in which NASA contributes to the solution of missile problems. The first way is through our general research programs. Our objective at NASA is to develop as much of the basic engineering technology, in the fields I have discussed in the previous chart, as we are able to provide in order to contribute to the design and development of advanced missile types. The results of NASA research investigations are made available to the military services and to all of the designers of missiles in this country. Our results have contributed importantly to the advancement of the Nation's missile program.

The second important way in which NASA talent is brought to bear on missile problems is by investigations of specific missiles. Here the NASA scientist brings to bear his skill and experience from the general research programs to improve the performance of a specific missile or to solve a particularly difficult problem which a specific missile has encountered.

NASA STUDIES OF SPECIFIC MISSILES

In the last several years our research centers have tackled over 100 problems of specific missiles. The names of some of these missiles on which we have worked are indicated on this chart. In this column here on your left are names of the interceptor missiles. In upper group are the names of the missiles which are ground launched.

This lower group are the air-launched interceptor missiles. The missiles in the center column are the winged bombardment missiles. At the top are the surface launched. At the bottom are the air launched.

In the last column on the right I think you will recognize the names of many of our ballistic missiles, and we have worked on all of the missiles listed here. One interesting point, I believe, is that many of the names you see here relate to missiles which are not yet operational.

Time would not permit discussing very many of these problems or referring to any extent to our general programs. But in order to give you a better feeling for our work in this area, I have selected a few typical examples of some of our specific studies.

CONTROL PROBLEMS

This chart is concerned with control effectiveness. By that I mean the maneuverability of a winged interceptor missile somewhat like this diagram.

This is an advanced version of an Air Force missile. The problem was brought to one of our research centers by the Air Force contractor. Now the problem concerns the control effectiveness of the hinge controls on the rear of the missile.

We see that the control effectiveness varies with increasing airspeed as indicated by this black line. You will notice that at the highest speed there is little control effectiveness, which means that the missile has little or no maneuverability at this speed. As a result of wind tunnel and rocket-powered model studies at our Wallops Island station, an arrangement such as indicated was proposed. With this new control arrangement, this control effectiveness or maneuverability was improved as indicated by the dotted blue line. We now see that at the highest speed the missile has much more control effectiveness and maneuverability. In fact we now have as much control effectiveness at high speeds as we had previously at 1,500 miles per hour.

Moreover, the control effectiveness has been increased at all speeds above 1,000 miles per hour. This problem of loss of control effectiveness of hinge controls with speed has been with us for a long time and has been the subject of a number of general research investigations at our research centers.

One arrangement discovered in these investigations is being incorporated at this time in the design of a new short-range ballistic missile, as indicated on this chart. The control arrangement I refer to is this stubby wedge-shaped control here. Now if we compare this new control with the size of a conventional control surface, as indicated by the dotted blue area here, to give equal lift or control effectiveness at 7,000 miles per hour, we see a number of interesting things. First, since this is a short-range ballistic missile ——— one of the requirements is that it be highly mobile. We have a shorter span, which helps. The stubby surfaces are also more rugged. In addition, this larger more conventional surface would be heavier structurally.

This new control arrangement was discovered during a general research investigation, and controls of this type, as you may be familiar from this morning's discussion have also been applied to an airplane, the X–15. You can see that our general research results are applicable both to missiles and airplanes.

BALLISTIC MISSILE PROBLEMS

You will hear later from Mr. Allen a discussion of NASA contributions to the solution of the heating problem of ballistic missile nose cones. I would like now to discuss briefly some of our other contributions to problems that have been encountered by ballistic missiles.

WIND VIBRATION PROBLEMS

First let's consider the missile when it is standing on the launching pad; when it is on the ground. It has been known for some time that tall smokestacks are susceptible to damage in high winds. In view

of the extremely light structure of ballistic missiles, it was suspected that perhaps a missile on the launching pad could experience damage by wind vibration.

So a model of a ballistic missile ——— was installed in one of our wind tunnels and tested. It was found as suspected that the lightweight structure of the missile was susceptible to wind damage due to vibrations when standing on the launching pad. The phenomena involved will be demonstrated by Mr. Hoboult in a later talk but I might explain it briefly here. If we consider a cross-section through the missile near the top; that is this black disk on the chart; and the wind is passing in this direction across the missile, we find there is an alternate shedding of what we call vortices. The little swirl of air here first came off of one side and this one off the opposite side and then again one here from this side and one here from the other side.

This alternate shedding of vortices can and in many cases will set up a vibration of the missile such as shown. One way of handling this is to put small strips at the top to break up the manner in which the vortices are shed. By application of such a device to this missile we find we can reduce the loads to about half of their original magnitude.

LAUNCH AND STAGE SEPARATION PROBLEMS

Another area in which we encounter quite a few difficulties with ballistic missiles is in the launching and stage separation phases of flight. In this area we find that our wind tunnels can give us a good deal of information to help. Now most of the problems in this area are unanticipated, for two primary reasons. The first is that a large number of variables are involved. The second reason is that the airflow is quite disturbed during these stages of flight. Here I have a picture of what you would see looking through the window of one of our wind tunnels during a stage separation test.

This test was run at supersonic speeds. Here is the way the model would be mounted initially for the launching, and in stage separation. The lower stage of the model is supported here, the upper stage separately here. You can see from the shock wave pattern and the air flow in this region a good deal of flow interference is involved. By investigations of this type we are able to simulate the various conditions of launching and stage separation and provide detailed measurements on the loading, the local heating and on the stability. This helps in the design of the structure and in the design of the control system. This type of investigation has now become standard practice in the development of ballistic missiles.

We have run investigations of this nature on Polaris, Titan, Pershing, and others including NASA space launching vehicles.

BASE HEATING

The next area I would like to discuss is the problem that was demonstrated quite vividly when we made our first attempts to launch ballistic missiles at Cape Canaveral a year or two ago.

In one instance after a beautiful takeoff there was a flash, an explosion and fire and the missile was destroyed. The military service

brought this problem to one of our research centers. What we call base heating was suspected.

A model of the missile with operating rocket engines was installed in one of our wind tunnels. In this chart we can show you what we found. The air flowing on the outside of the missile at about the speed of sound, in this stage of flight was drawn up into this base cavity, and as it passed over the hot rocket nozzles, it was heated. In addition fuel-rich mixtures were exhausted from a turbine here, which were also drawn up into this cavity and heated.

Temperatures measured in our tests were as high as 1,400° F. This was all that was needed to cause an explosion.

Senator STENNIS. This was what?

Mr. AMES. All that was needed for an explosion. As a result of NASA tests, a recommendation was made that the missile be modified as indicated here, so that cool air was drawn in to scavenge this area, and provided some additional cooling to the rocket nozzles. In addition this exhaust pipe was lengthened so that the fuel-rich mixtures were carried downstream.

These changes resulted in reducing the temperatures in the base region. There were also two favorable byproducts of the investigation. The drag or the resistance of this missile was reduced by the modified arrangement. Also the rocket nozzles swivel for control, and in this instance the forces required to move these nozzles were very large and erratic. In the later configuration the controlling moments on the nozzles have been reduced and now vary much more regularly than they did in the earlier arrangement.

Investigations on the base-flow and base-heating problem of missiles have now been conducted by NASA on the Jupiter, Atlas, Titan, Pershing, Thor, and are planned for the Minuteman and Polaris.

INSTABILITY OF BALLISTIC MISSILE NOSE CONES

The last problem area I would like to discuss is one concerned with the stability or perhaps more accurately the dynamic instability of reentry models or bodies such as a ballistic missile nose cone.

To orient you, ballistic missile nose cones enter the atmosphere at velocities between 12,000 and 15,000 miles per hour.

These nose cones decelerate rapidly as they penetrate the atmosphere and experience increasing atmospheric density, and before impact, just before impact, they are moving at speeds considerably less than the initial velocity of entry. Obviously during this entry they must not burn up, but they must also be stable. The first is that if they are not stable, they may oscillate in such a manner as to burn un-

protected parts of the nose cone. If they are unstable, we could not expect them to reach the target with any reasonable degree of accuracy. This stability problem has been investigated throughout the entire speed range in both general research and specific development programs at our centers using the various pieces of research equipment which we have.

The record I have here was obtained at about the speed of sound from a rocket-powered model at our Wallops Island station. It is a telemetered trace of the angle of attack, which is the attitude of the missile to the direction it is falling which varied with time, in seconds. The time for this entire record is only 1 second. I think I can show you better what is going on if I turn the chart sidewise. The phenomena here occurred just before impact and this is one place we do not want anything of this sort to occur.

Here is the body when it was distributed initially so that it went to an angle of about 8 degrees. There is a slight tendency for it to come back to zero, but it again persists in moving on out until at the end of the 1 second time period it was at an angle of 25 degrees in the direction in which it was falling.

The configuration here is somewhat similar to the configuration which would be used on an early version of one of our ballistic missiles.

We certainly could not tolerate an instability of this nature, and this problem is one that is not solved completely to our satisfaction yet. I would certainly like to assure you we are working hard on this problem to get a better understanding of what is taking place. A number of possible solutions are in mind. They involve some weight penalty and we would like to find a way around that.

Senator STENNIS. You say it is one of your problems now?

Mr. AMES. This is one that is not completely solved to our satisfaction.

Senator STENNIS. In some of the more advanced ones?

Mr. AMES. No, with the more advanced missiles the shape is not as blunt as this and I don't think the problem would be as bad.

I would like to summarize briefly two primary points of my discussion. The first is that NASA research centers contribute importantly to the solution of missile problems through their general research programs. Here we are striving to provide the advanced technology in these areas I have discussed which is required to insure that we are able to design advanced missiles.

Secondly, by specific investigations of problems of particular missiles, we are able to effect solutions in important areas.

Thank you.

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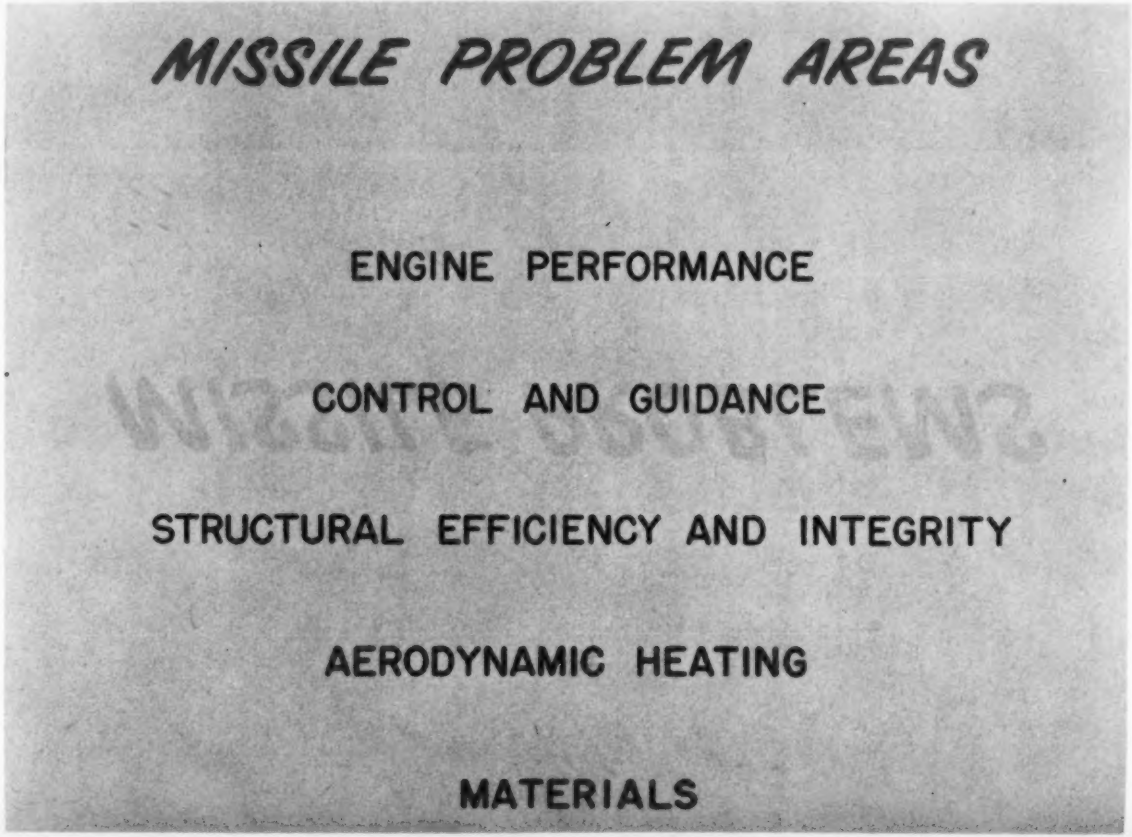
MISSILE PROBLEMS


MISSILE PROBLEM AREAS
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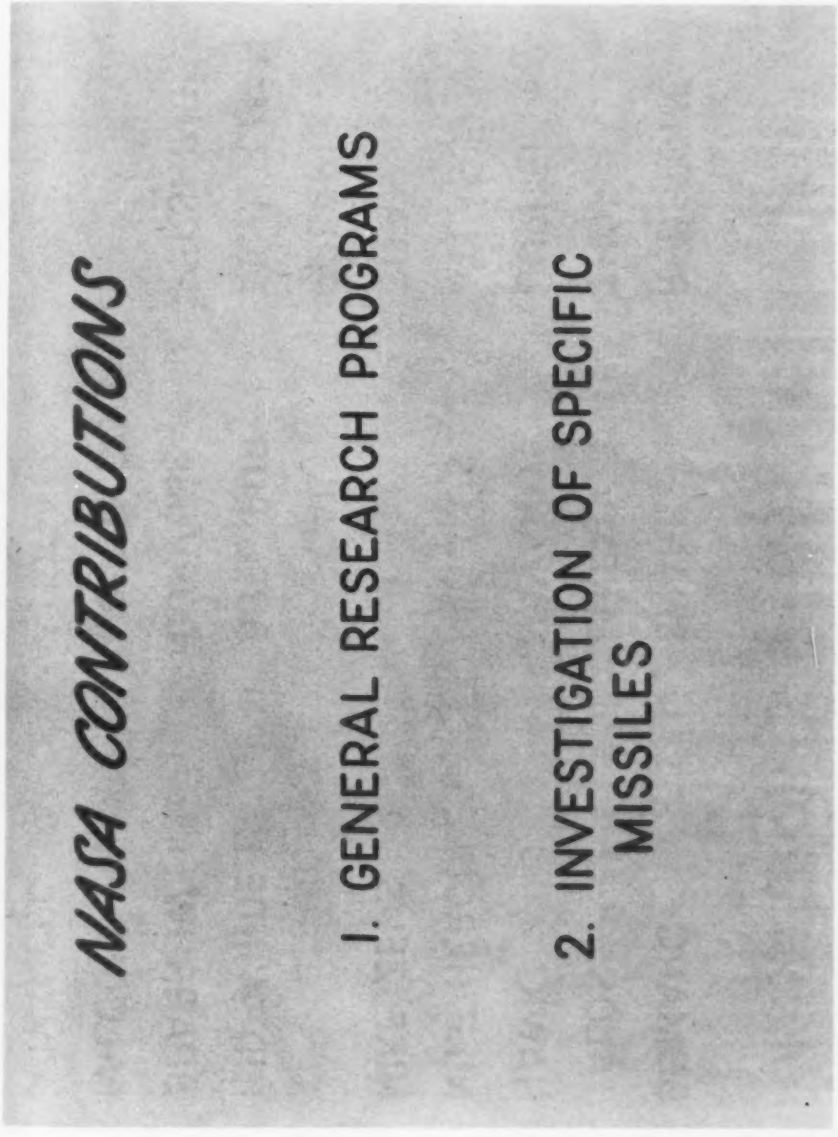
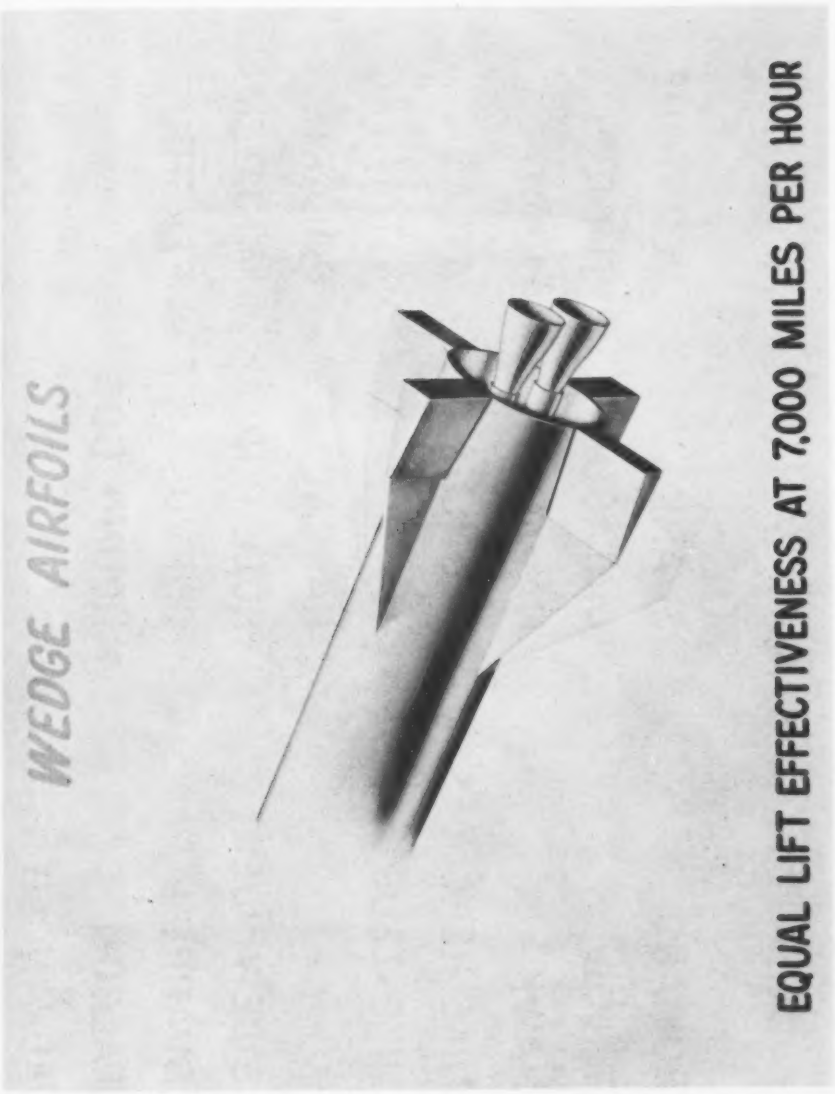
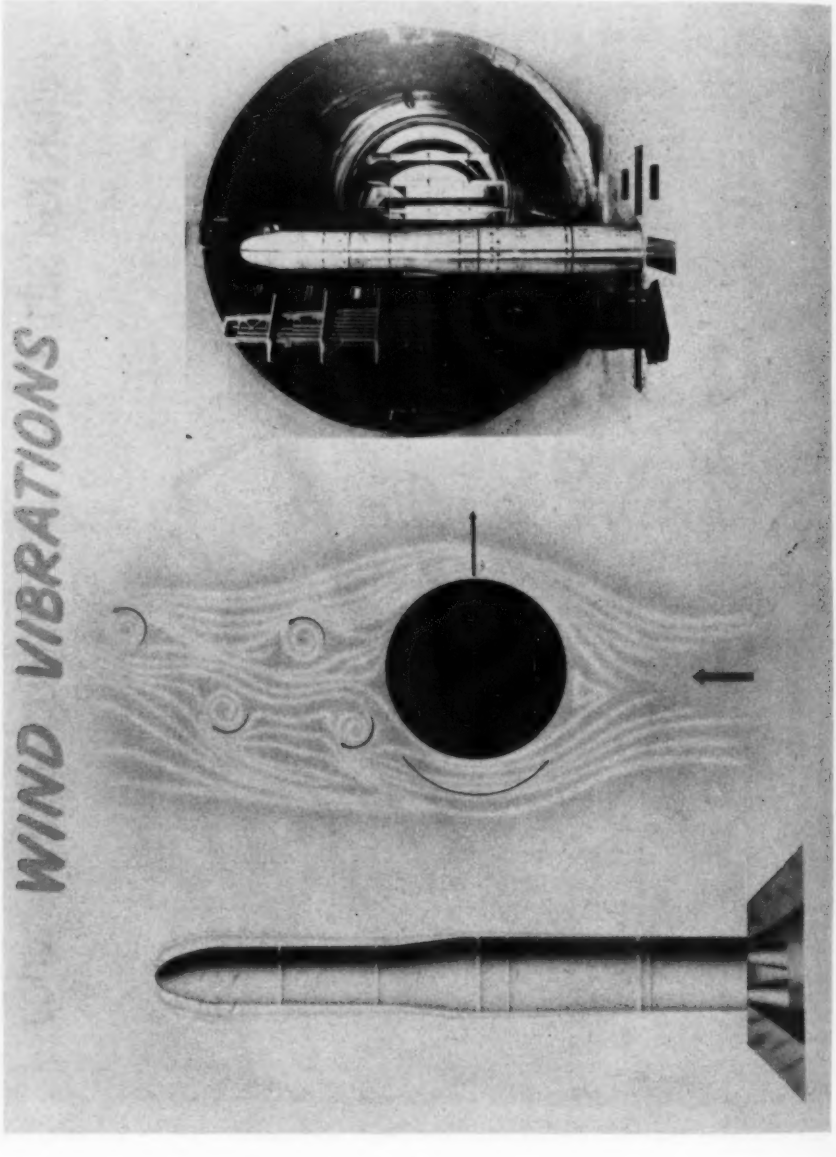
CONTROL AND GUIDANCE
STRUCTURAL EFFICIENCY AND INTEGRITY
AERODYNAMIC HEATING
MATERIALS

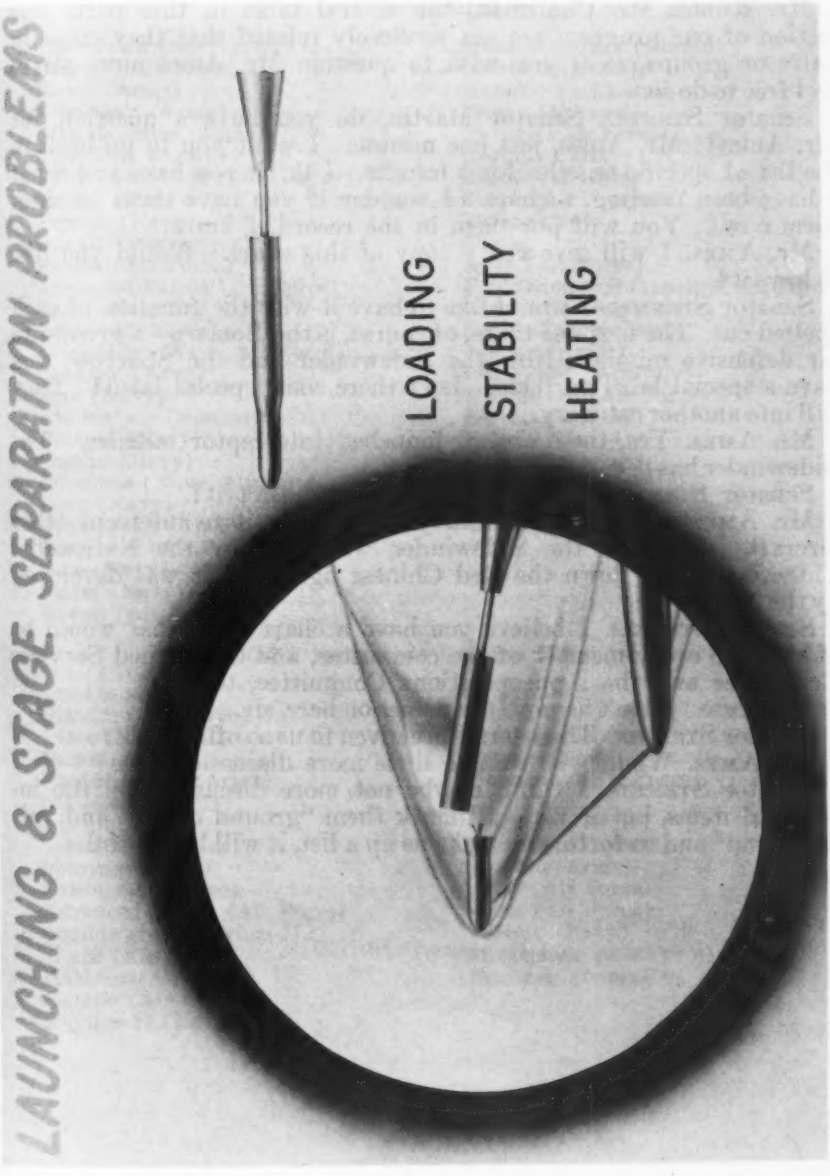

NASA CONTRIBUTIONS
1. GENERAL RESEARCH PROGRAMS
2. INVESTIGATION OF SPECIFIC MISSILES

NASA STUDIES OF SPECIFIC MISSILES

BOMARC	SNARK	REDSTONE
TALOS	MATADOR	THOR
HAWK	NAVAHO	JUPITER
NIKE HERCULES	REGULUS II	ATLAS
NIKE ZEUS		TITAN
	RASCAL	POLARIS
SIDEWINDER	BULL PUP	MINUTEMAN
SPARROW	CORVUS	PERSHING
FALCON	HOUND DOG	
ADVANCED FALCON		


WEDGE AIRFOILS
EQUAL LIFT EFFECTIVENESS AT 7,000 MILES PER HOUR


WIND VIBRATIONS


LAUNCHING & STAGE SEPARATION PROBLEMS
LOADING
STABILITY
HEATING

Senator STENNIS. We certainly do thank you, Mr. Ames. I will have a question or two later. You will indicate the breaking point here, Mr. Rhode.

Mr. RHODE. Mr. Chairman, the several talks in this particular section of our program are not so closely related that they come in pairs or groups, so if you wish to question Mr. Ames now, please feel free to do so.

Senator STENNIS. Senator Martin, do you have a question for Mr. Ames? Mr. Ames, just one minute. I want you to go back to the list of specific missiles for a minute. I think you have just what I have been needing, a chart. I wonder if you have those in sheet form now? You will put them in the record, I know.

Mr. AMES. I will give you a copy of this chart. Would you like to have it?

Senator STENNIS. I would like to have it with the function of each spelled out. The first one there, of course, is the Bomarc—a ground to air defensive missile. Now the Sidewinder and the Sparrow, you have a special label on them. Isn't there some special label? They fall into another category.

Mr. AMES. Yes, these are air-launched interceptor missiles. The Sidewinder has been carried by——

Senator STENNIS. It has been dropped, hasn't it?

Mr. AMES. Air Force and Navy fighters use it to intercept other aircraft. I believe the Sidewinder was used by the Nationalist Chinese to shoot down the Red Chinese fighters. It was developed by the Navy.

Senator STENNIS. I believe you have a chart there that would be of value to every member of the committee, and the Armed Services Committee and the Appropriations Committee, too.

Mr. AMES. I don't have all the names on here, sir.

Senator STENNIS. These terms are given to us so often.

Mr. AMES. Would you want a little more discussion here?

Senator STENNIS. I think maybe not more discussion on the individual items, but if you will mark them "ground to air" and "air to ground" and so forth, and make us up a list, it will be helpful.

(The following information was subsequently provided by NASA:)

U.S. MISSILES

Surface to air (interceptor):
- Bomarc (Air Force)
- Hawk (Army)
- Nike-Ajax (Army)
- Nike-Hercules (Army)
- Nike-Zeus (Army)
- Talos (Navy, Air Force, Army)
- Tartar (Navy)
- Terrier (Navy)

Air to air (interceptor):
- Falcon (Air Force)
- Advanced Falcon (Air Force)
- Eagle (Navy)
- Genie (Air Force)
- Sidewinder (Navy, Air Force)
- Sparrow (Navy)
- Zuni (Navy)

Air to surface (bombardment):
- Bullpup (Navy)
- Corvus (Navy)
- Crossbow (Navy, Air Force)
- Dove (Navy)
- Green Quail (Air Force)
- Hounddog (Air Force)
- Lulu (Navy)
- Petrel (Navy)
- Rascal (Air Force)

Surface to surface (winged):
- Lacrosse (Army)
- Matador (Air Force)
- Mace (Air Force)
- Navaho (Air Force)
- Regulus I (Navy)
- Regulus II (Navy)
- Snark (Air Force)
- Subroc (Navy)

Ballistic:
- Atlas (Air Force)
- Bold Orion (air-launched, Air Force)
- Corporal (Army)
- Honest John (Army)
- Jupiter (Army)
- Little John (Army)
- Minuteman (Air Force)
- Pershing (Army)
- Polaris (Navy)
- Redstone (Army)
- Sergeant (Army)
- Thor (Air Force)
- Titan (Air Force)

NASA STUDIES OF SPECIFIC MISSILES

Ground to air:
- Bomarc (Air Force)
- Talos (Navy)
- Hawk (Army)
- Nike-Hercules (Army)
- Nike-Zeus (Army)

Air to air:
- Sidewinder-(Navy)
- Sparrow (Navy)
- Falcon (Air Force)
- Advanced Falcon (Air Force)

Ground to ground (winged):
- Snark (Air Force)
- Matador (Air Force)
- Navaho (Air Force)
- Regulus II (Navy)

Air to ground:
- Rascal (Air Force)
- Bullpup (Navy)
- Corvus (Navy)
- Hounddog (Air Force)

Ballistic:
- Redstone (Army)
- Thor (Air Force)
- Jupiter (Army)
- Atlas (Air Force)
- Titan (Air Force)
- Polaris (Navy)
- Minuteman (Air Force)
- Pershing (Army)

Senator STENNIS. Senator Martin and I were down at Cape Canaveral and saw the launching pads there for Polaris. Frankly I was disappointed that it did not show signs of more advanced development. I know that the missile itself is being made in California.

Mr. AMES. Yes.

Senator STENNIS. You said the manufacturer had successfully launched a missile from under water. Was that Polaris?

Mr. AMES. That was Polaris but they did not launch it for its entire trajectory. That was only to prove or to study problems encountered in getting it from say a submarine out of the water into the air. That phase of the program has been undertaken on the west coast. We have also studied the problems that might occur during this stage of flight by using model tests at the Langley Research Center.

Senator STENNIS. Where is the main launching site of the Polaris to be, at Cape Canaveral?

Mr. AMES. As I understand it they will continue to launch their test vehicles at Canaveral. I believe also the Navy plans to test later versions from their base at the Pacific missile range. I don't know the details of their plans there, sir. I do know about the moving launching stand that they have in Florida, as you saw yourself.

Senator STENNIS. I understood that that was not really in operation yet.

Mr. AMES. It is an engineering problem to make it work and simulate the rolling of a ship.

AIR-LAUNCHED BALLISTIC MISSILE

Senator STENNIS. One more question. Has NASA done any work on the air-launched ballistic missile?

Mr. AMES. We have not worked specifically on the missiles being studied for the Air Force. I believe this is correct. We have studied for many years the problems of launching various kinds of shapes from airplanes in flight. We are quite familiar with the problems and we are in close touch with the people trying to do this full scale.

Senator STENNIS. In close touch—you mean with the Air Force?

Mr. AMES. With the Air Force and the companies involved. You see, the manufacturers' engineers come to us at our centers, and talk quite freely about their problems and they find out what we have learned even before we publish our reports. We find out where they are running into trouble and we feed these problems back into our program.

Senator STENNIS. But you don't have any special project on that idea itself?

Mr. AMES. Not on the specific weapons system that you have in mind, though I do want to assure you that we are familiar with these problems.

Senator STENNIS. How far along is the Air Force in this project? Do they have any contracts made or in the development stage? Can you give me a little on that?

Mr. AMES. I do not know myself of any contract to end up with the weapon system. I do know of contracts to run experiments to determine the feasibility of such a system.

Senator STENNIS. Mr. Rhode, do you know whether it is beyond the contracts for research and feasibility?

Mr. RHODE. No, sir, I do not. I am afraid this is something I would have to refer you to the military on, sir.

Senator STENNIS. Mr. Lehrer, would you know that?

Mr. LEHRER. Yes, the Air Force has just announced, according to the newspapers, that they have requested specific bids and intend to award a contract very shortly.

Senator STENNIS. For what?

Mr. LEHRER. For the development of a specific air-launched ballistic missile.

Senator STENNIS. Development?

Mr. LEHRER. I think the significant question that might be explored is, is it rather unusual for the military to be at the point of awarding a development contract without your agency having participated in the early research and development stages?

Mr. AMES. I would like to make one point here. It is not exactly a direct answer to your question. I realize this, but we have provided a good deal of information which permits the designers of such a weapons system to take first steps in designing ballistic missiles which would be air-launched. I know that the people at the Martin Co. have discussed this problem with us, and the people at Convair have discussed this with us, and we know something of the work they have been doing. Now we have not been asked specifically by the Air Force to work on a specific system, because the Air Force has not gotten to that stage.

But in a general sense we are aware of the kinds of things they would experience, and we have a great deal of background in air launching of all kinds of shapes. These missiles are air-launched. And of course, they would not have wings. For example, the Hounddog is air-launched from the B–52, and we have worked on this.

Mr. LEHRER. May we ask were you involved at a comparable stage in the development of the Minuteman? Was NASA involved in the research and development?

Mr. AMES. I think so. Mr. Allen here, who will speak later, has been a consultant to the Ballistic Missile Division on reentry of missiles, and on the Air Force plans for advance ballistic missiles following Atlas and Titan. I think he is prepared to answer that.

Senator STENNIS. All right, we will ask Mr. Allen to cover that when he comes up.

Is there anything else? Thank you very much, Mr. Ames.

Mr. Rhode?

Mr. RHODE. Thank you, Mr. Chairman. I know that you have biographical sketches of all of the speakers, sir. I haven't seen them myself and I don't know just what appears on them. Because you have them I have made no point of mentioning the specific accomplishments of individual speakers. Many of them, as I am sure you are aware, have been given various honors and awards for their individual scientific accomplishments in aeronautics and space.

Senator STENNIS. I have been impressed with those that I have had a chance to read, Mr. Rhode, and we said this morning that we would put these sketches in just after the witness' name appears, and that is what the reporter will do in each case.

Mr. RHODE. I just wanted to mention, with that much of an introduction, that our next speaker, Mr. H. Julian Allen, has received the Air Force award and NACA gold medal for his accomplishments in the area in which he is going to speak.

You may recall that the ballistic missile, the long-range ballistic missile, became a feasible concept as a consequence of two developments. One was the development of the hydrogen bomb and the other was the concept or development of the blunt-nose cone which made the aerodynamic heating problem tractable. Mr. Allen conceived the blunt-nose cone solution to the ICBM warhead reentry problem and this is one of the two major factors in the feasibility of the ICBM. Mr. Allen is going to speak on the subject of atmospheric entry of ballistic missiles.

Senator STENNIS. Thank you very much. Mr. Allen, we are very glad to have you indeed. We are delighted to hear what you are about to say and are proud of your accomplishments.

TESTIMONY OF H. JULIAN ALLEN, CHIEF, HIGH-SPEED RESEARCH DIVISION, NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.

Mr. ALLEN. I would like to talk about some of the problems that are associated with the entry down through the atmosphere of ballistic missiles, in a very fundamental way, so that you can see what the nature of these problems are. I will discuss some of the solutions of these problems. Then I would like to show how these same solutions have been employed in some of our current vehicles.

BALLISTIC MISSILE TRAJECTORIES

As you know, when you throw a ball you throw it further if you throw it faster. But in addition to that, and an important point, is that you will throw it further for a given speed, if you throw it at a particular angle, which happens to be about 45 degrees, when we are essentially in short ranges.

Now we are interested in these optimum angles of attack because this requires the least energy input for a given range. When you come to ballistic missiles the same thing is true. The speed, of course, is considerably greater because you are talking about thousands of miles instead of hundreds of feet, but it is still true that there is an optimum angle to throw this vehicle at, for which you will have to provide the least velocity for the given range.

You are attracted to use such optimum paths, trajectories, because in that way we don't have to supply any more thrust for any longer period than is absolutely necessary, and as a result it keeps the missile smaller.

On this chart I have tried to show what these optimum trajectories look like. First the vehicle is boosted vertically. This is done principally to get the vehicle out of the atmosphere as soon as possible so that its aerodynamic drag and the aerodynamic heating that is

associated with it don't become active during this phase of the flight. Then at this point the guidance system gives the vehicle command to turn such that at the end of the powered flight it is flying the beginning of the optimum trajectory.

You will notice the interesting point about this is that the optimum trajectory for the IRBM, which is shown here, the optimum angle is a steeper angle, than it is for an ICBM, and in turn the angle does go to zero as you go to satellite speeds because you are just flying tangentially with respect to the earth. This has an important bearing on some of the problems that have come up, the fact that this optimum angle decreases with increasing range.

MAXIMUM DECELERATION DURING ENTRY

One of the first things that I would like to talk about is the motion or the retarding forces that are experienced by a ballistic missile. In this connection it is an interesting fact that the retarding force as plotted here as a function of range is seen to rise to a maximum value at around 5,000 miles. It amounts to something a little less than 60 G's deceleration. The reason that it increases at first is because the velocity is increasing. In other words, when it comes back into the atmosphere, the velocity is very much higher since the product of the square of velocity times the density, the force is naturally increasing with increasing range.

The reason why it decreases on the other side, however, is due to the falling. Even though the speed is increased the angle is becoming sufficiently flat that the rate of increase of density with time offsets this effect, so that the vehicle experiences lower loads. In other words, the forces act for a longer period of time. You can see here as we discussed earlier, as I say we get up to about 60 G's in this range. When we get to satellite speed we have to go through a period of around close to 8 to 10 G's, something in that order.

The interesting point I think here though is this: I haven't discussed the shape of this thing at all or its weight. The reason I haven't is because it has no bearing on the problem. These forces are experienced irrespective of what the shape of the vehicle is or its weight. The only way that they will not be reached is if it hits the ground before this maximum value is reached. Otherwise, if it is reached within the atmosphere, it is independent of the shape. Therefore, there is no indication about what a vehicle should look like, looking just at the deceleration, and this is not a particularly difficult problem to provide a structure which will stand up under this sort of a load.

STATIC STABILITY

Let's now look at the problem of stability. This is a field in which the shape has considerable effect. First, I would like to talk about the static stability. I know you have heard a lot of these terms around here. I would just like to go through it again to be sure you stay with me. As the vehicle comes in from outside the atmosphere it may be faced in another direction than the way in which it is traveling.

We say it is statically stable if, when it enters into the atmosphere and begins to feel the aerodynamic force, the aerodynamic force

tends to turn the nose first in attitude. It is statically unstable if it wants to turn around, and obviously we are interested in having a statically stable vehicle because otherwise you will get into all these problems that Mr. Ames discussed.

So the question is how does this vary with shape? This next plot I think will demonstrate some characteristics about the effects of shape on this. You see, the center of mass of the vehicle will lie across it at or near the center of volume of the body because if you just distribute the parts around in there uniformly you would be at the center of volume.

Let's take the case of a very blunt shape of this type. The forces which act on it act perpendicular to the surface, so they tend to intersect at a point behind the missile, in other words behind the center of mass. So, consequently, if on this vehicle when it is in this direction this force increases, this other one decreases, and the result is that there is a net moment to right it. This kind of a shape, in other words, tends automatically to be stable, to be statically stable. On the other hand, if we go too far with this business it is possible, for example; to have these lines intersect on the center of mass, in which case it has neutral stability. It has no tendency to return at all. Long, slender shapes tend to be unstable in this respect, so, consequently, from the static stability point of view we favor very blunt shapes.

I would like to introduce another concept of stability which is what we term dynamic stability. If we take a statically stable vehicle, that is, one that wants to be turned to zero—of course it will overswing like a pendulum. It goes over to the other side and then it comes back, and so on, and if in these ensuing swings it damps out, we say it is dynamically stable. If on the other hand it swings further and further it will eventually tumble.

We found in considering dynamic stability that when a vehicle first enters the atmosphere the fact that the density is increasing very rapidly and the vehicle is still moving fast makes practically any vehicle stable dynamically. But near the lower part of the trajectory, and this is the region which Mr. Ames was talking about, the problem near the speed of sound, for example, we have found that in that range the dynamic stability is an important item. And we have to try to lick this problem. We have found that one of the most serious shape factors as far as dynamic stability is concerned is if the vehicle is too blunt in front, or if the face is flat, the vehicle tends to be dynamically unstable through a rather large range. However, if we go even to a little more conical shape than that, we find this immediately is made satisfactory and shapes like this are quite satisfactory.

So far what we have seen is that as far as the loading is concerned the shape is of no importance. As far as the stability is concerned we want relatively blunt shapes but we don't want them too flat faced. But this gives us plenty of latitude as far as the shape is concerned. But the thing that determines really what happens to that is the aerodynamic heating, because this is the problem which is the most serious for these vehicles. As you are all familiar, these things are going to become meteors and like most meteors if you don't pay enough attention to them they burn up on the way down because

the energy that is available far exceeds the heat that would be required to vaporize them.

So we have to be very careful that we don't put in a large fraction of this energy into the vehicle.

FLOW ABOUT SLENDER AND BLUNT BODIES

Now, as you know, the way in which heat enters the vehicle is through the shearing forces that go on in the air that is close to the surface. We call this little thin layer around the surface the boundary layer, and it is the work done in shearing these layers that promotes these high temperatures in the air which in turn can be transmitted to the vehicle. So the question is how do you get around this thing?

And that is what I would like to discuss. There are two aspects of this problem that I would like to discuss. One is a consideration of the total amount of heat that goes into the vehicle, because this determines the amount of material which has to act as coolant. On the other hand, we are also interested in another phase of it. That is we are also interested in what is the maximum time rate of heat input, how rapidly does the heat go into it, because this in turn determines not so much the amount of the material but rather the kind of material. I will try to show how this is.

On this chart I have shown the amount of the heat—these are simple round nose cones here—I have tried to show the amount of heat in millions of British thermal units, as a function of the cone angle.

Because you probably are not familiar with a British thermal unit, one of them is enough to raise 1 pound of water 1° F. but a better way to look at it is this is the amount of heat it takes per pound to melt, to bring copper up to melting. So what this means, you can see right here, is that I have to at least have a 40° cone angle. Otherwise even at 40° cone angle the thing will melt away. If it were made of solid copper with no payload of all——

Senator STENNIS. If what?

Mr. ALLEN. If it was made of solid copper it can't even bring itself down much less protect a payload so we have to get out to a cone angle of about 100° in order to bring this down to a satisfactory value, to get down to the point where the heat sink is of less weight than the payload. Otherwise all you are really doing is you have to provide the coolant to keep the coolant cool. That is what it amounts to, and that is a rather poor and uneconomical way to handle this business.

So, to show why this state of affairs exists, I think I can show it with these two pictures. One, we use what we call shadows. They are taken of models in flight and they show the main disturbances that exist in the airstream. Along this edge here I think you can see the boundary layer as it develops. You can see it is probably the principal disturbance in this field. These waves are strong but still not as prominent as this boundary layer. On the other hand, in this field you see that on a blunt body you can't even see the evidence of the boundary layer here. It is a minor disturbance compared to this very, very intense shock wave.

What that means is that in this case with the sharp nose the principal shearing that is going on is right next to the body so that the

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body takes in this heat. In this other more blunt case the shearing that is going on is going on out in the atmosphere, in this wave in front of it. Consequently since practically all of the energy the vehicle has when it comes in has to be converted to heat, by going to a blunt shape you give the heat to the atmosphere so you don't have to take it on yourself. A shape like this, for example, something like 35 percent of the total amount of energy will go into the body. In this other case about a half of 1 percent, so that is the way you solve this kind of a problem.

RATE OF AERODYNAMIC HEATING

Now, the next feature I would like to discuss is this business of the time rate of heat input. The reason this is important is that you can readily see that these heat rates are always at a very great rate, so that the outside gets very hot, much faster than the inside does because the heat simply can't run in fast enough.

You know whenever you do this kind of thing, heat one side and not the other, the thing wants to change its shape but it is held from being able to change its shape. Consequently it develops stresses inside which tend to cause failure if the temperature difference is too great. So we are interested in getting down to low rates of heat input. In this regard it so happens that the same solution applies. One of the features of these vehicles is that the heat rate is reduced if you increase the radius of curve on the surface, and, of course, that goes right along with the idea, the concept of using a fairly blunted shape. In other words, you would never use a pointed vehicle. If you have ever taken a needle and held it in a flame and looked at it with a microscope you find out even if you left it there, just passed it through, the sharp point which was on the needle is gone because obviously it has no heat capacity. It has no place for the heat to go so it simply burns it off. So the vehicle should be rounded all over.

That brings us to these kinds of shapes. I have tried to discuss here just some of the fundamental ideas back of what constitutes these problems, what these problems are, and how you can best solve these problems.

CURRENT BALLISTIC MISSILES

At the present time the best solution has been the solution of using a blunt shape. On this graph I have shown the nose cones for four of the vehicles we have at the present time. The Thor and the Atlas, which are almost the same except for differences in weights, the Jupiter and the Polaris, but the essential feature in all cases is that they are relatively blunt bodies. They are not long, skinny things we used to think were the right kinds of shapes. Of these four, these two are protected with copper. Copper has some very good attributes and some rather poor ones, but it is good in that it has the very high thermal conductivity as you well know. If you heat one end of a copper body the other end gets hot very rapidly. Consequently, there is very little trouble about thermal stresses developing to buckle the shell. On the other hand, it doesn't carry away as much heat per pound as some other materials do, and although it is very nearly as good as most metals it is not as good as some.

Now, with the more advanced Polaris, in that case we use beryllium which is superior to copper from the point of view that it will carry away more heat per pound. Consequently it is a better material from this point of view. On the other hand, I think it is not quite so good from the point of view of thermal stress, but it has been shown to be satisfactory in this particiular case. In the case of the Jupiter, a different method is used. We used glass fibers which were bonded with plastic. The idea here was not only to let this melt but actually to encourage it to melt and in fact encourage it to vaporize. It is a material with a poor thermal conductivity and it simply vaporizes.

As you know, it takes far more heat to vaporize something than it does just to bring it up to the melting point. For example, you readily recognize if you had ice at the minus 100 degrees you would do a lot better to bring it all the way up into steam. You can carry away a lot more heat. In fact it is a factor of about 10, in that order, between 10 and 30, so that it allows a big reduction in the weight of the heat shield. In the case of the Jupiter this was tried and found to work very well, and in fact the more modern schemes are based on the use of ablative surfaces; that is, surfaces that are purposely vaporized. Of course, we can get away with that because we don't expect to use it twice so if we lose some of the surface it is not an important point. So with the use of these ablative surfaces it is possible to greatly reduce this weight involved in the heat shield. Now there are some tricky problems about this that make it undesirable. But certainly this type of solution will probably find more use.

EFFECT OF SHAPE ON VELOCITY

But the last chart I would like to show you is one more thing that would be an advantage by using the ablative materials. Since the ablative materials carry away far more heat, we don't have to go to quite such blunt shapes. So this advantage of going away from blunt shapes is shown here. The general way in which speed varies with altitude is in a manner like this. When the drag is high, there is a fairly long period in the altitude where the speed is low, and the principal disadvantage of that is that the vehicle is then subject to wind drift as it comes down, and although you may have locked it to the right locality, if it spends too long coming down it will drift off the target before it hits the ground. Consequently we would like to reduce the drag for this purpose if for no other. So I think you will see that the improved versions of ballistic missiles will go toward less blunt shapes than we use at present, and I think that about covers what I have to say about this.

Now with respect to the Minuteman, this is one of the things that is being done with the Minuteman. Since the days when the first vehicles were started, the Atlas and so on, a lot has been learned about what we should not do over again. Some people would term those the model T versions. They are a little more expensive than the model T's were but they are connected with it in a way. With the Minuteman we are taking advantage of a number of gains that have been made in propellants. In guidance systems, improving the guidance systems, and certainly in this field we are taking advantage of

the improvements that have been made in the coolants for these nose cones and so on.

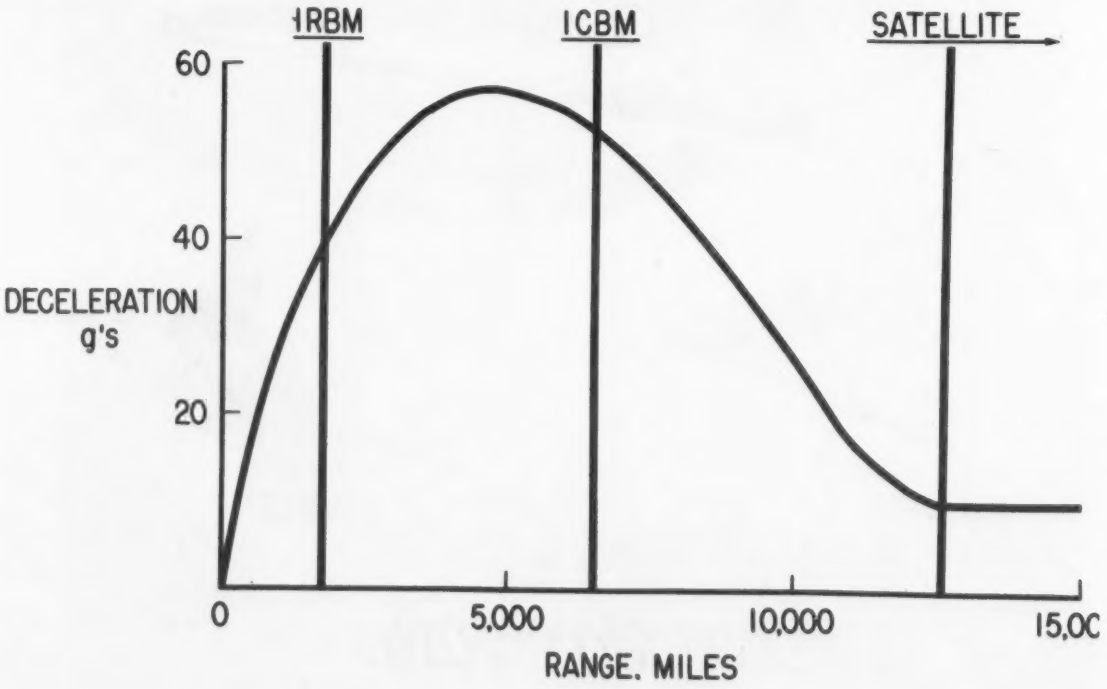
The result is that the vehicle is a lighter weight vehicle and fundamentally should be a better vehicle. But what we would like to do is to bring these vehicles down to a size where they could be field-launched instead of having specific launching sites because it is too easy for somebody else to find out where you are going to launch from. So this would be the important direction. I think these are just some of the problems that go into trying to improve these vehicles in this direction. That is all.

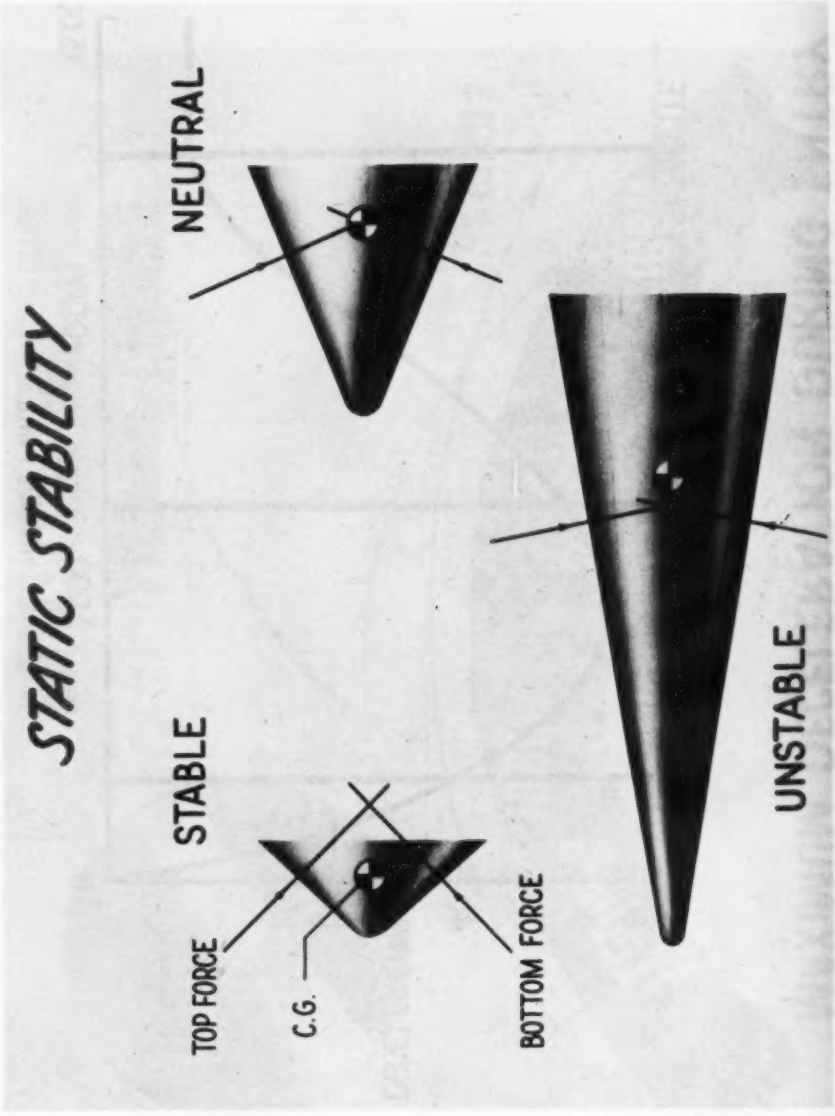
Thank you.

ATMOSPHERIC ENTRY OF BALLISTIC MISSILES

MAXIMUM DECELERATION DURING ENTRY

MAXIMUM DECELERATION DURING ENTRY

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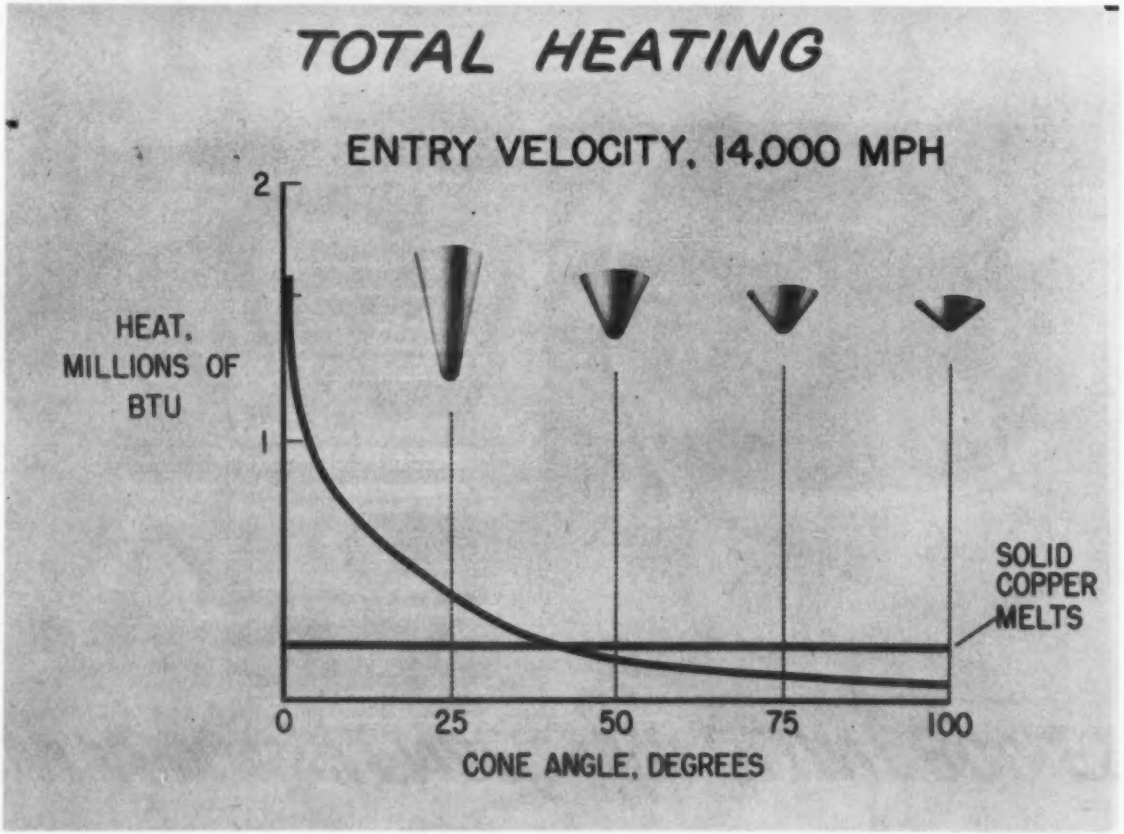
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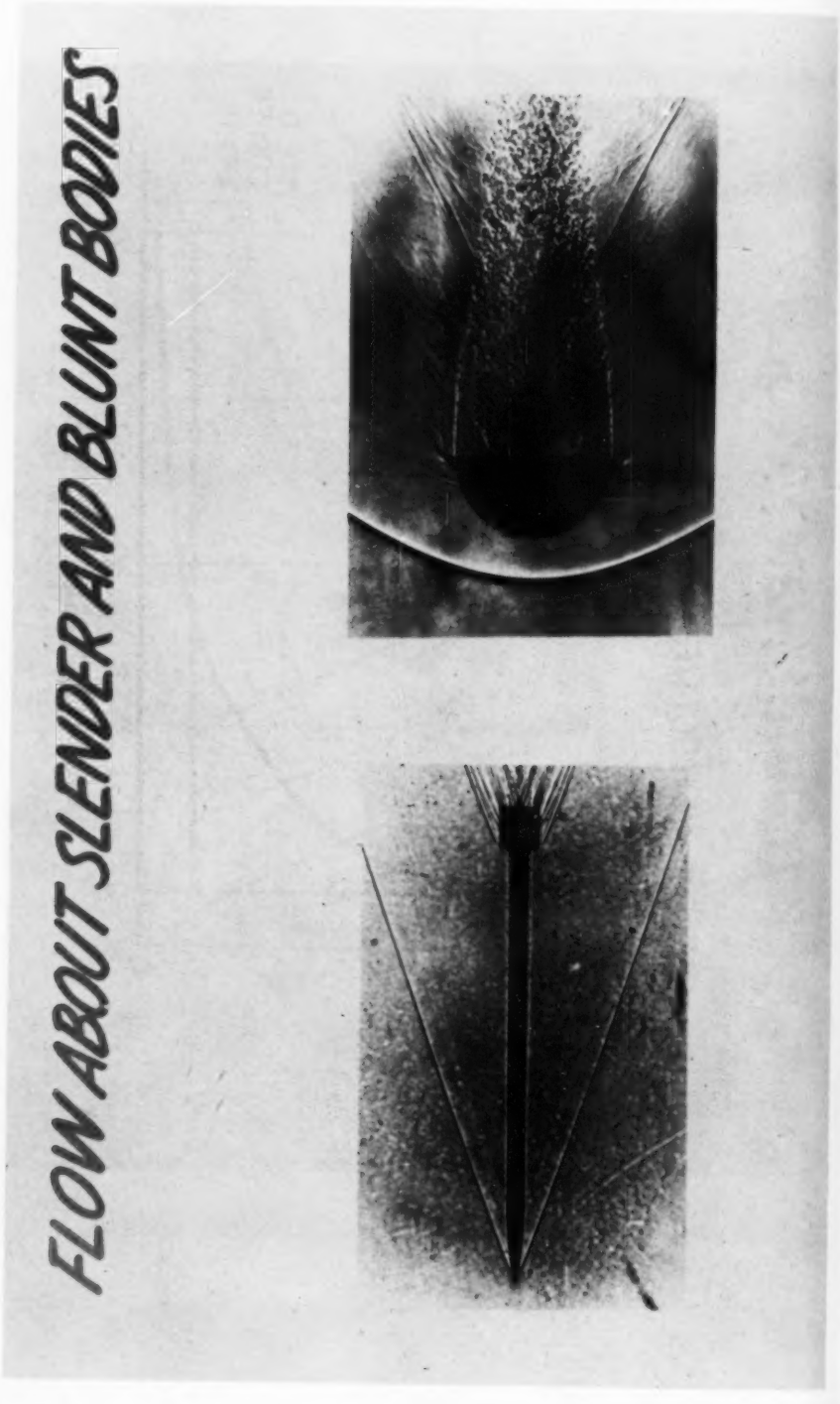
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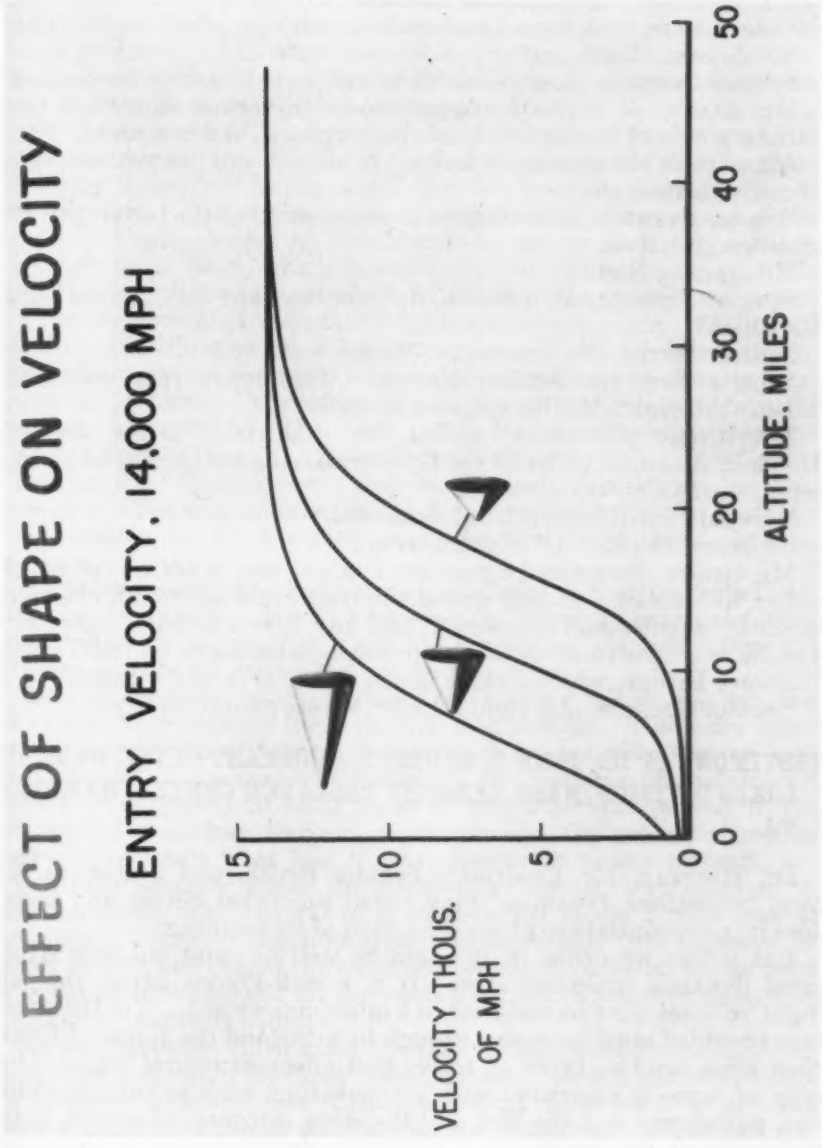
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ALTITUDE, MILES

Senator STENNIS. Thank you very much, Mr. Allen. We might ask Mr. Allen just a few questions now. I just want to be sure that I got the summary correctly that Mr. Allen gave with reference to the Minuteman. It is in some measure a consolidation of gains and advanced steps that have been made in various other undertakings.

Mr. ALLEN. Right.

Senator STENNIS. And you think it is going to be a superior product?

Mr. ALLEN. It is just an improvement in various directions from various points of view. Guidance, powerplants, and heat sinks.

All of these things simply lead up to a much smaller vehicle, which of course is desirable.

Senator STENNIS. It represents a combination of the better qualities of several relatives.

Mr. ALLEN. Right.

Senator STENNIS. Mrs. Smith, did you have any questions to ask of Mr. Allen?

Senator SMITH. No questions. Thank you.

Senator STENNIS. Senator Martin? Thank you very much, Mr. Allen. All right, Mr. Rhode, who is next?

Mr. RHODE. Our next speaker, Mr. Chairman, is Dr. John C. Houbolt, Assistant Chief of the Dynamic Loads Division at our Langley Research Center.

His subject will be structural dynamics.

Senator STENNIS. All right, Doctor.

Mr. RHODE. Structural dynamics, I might say, is not a problem peculiar to missiles. It cuts across the board and affects all classes of aircraft, missiles and spacecraft, and any time you have a structure you have a structural dynamics problem, whether it be the Takoma Narrows Bridge, which shakes in the wind, or a spacecraft.

Senator STENNIS. All right, Doctor, we are glad to have you.

TESTIMONY OF DR. JOHN C. HOUBOLT, ASSISTANT CHIEF, DYNAMIC LOADS DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Dr. HOUBOLT. Mr. Chairman, Senator Smith, and gentlemen, the term "structural dynamics" may sound somewhat obtuse and therefore it is appropriate to give a definition of its meaning.

But before we define it, it might be well to point out how structural dynamic problems arise. It is a well-known axiom that all flight vehicles must be designed to a minimum weight. Yet the structure provided must be strong enough to withstand the forces of flight. Now there are two types of forces that affect structural loads. One type of force is associated with maneuvering, such as turning, pullups, pushdowns and the like, and the other category, of course, is associated with the flexibility or vibratory characteristics of the structure. The flexibility or vibratory characteristics lead to the structural dynamics problems. As Mr. Rhode pointed out, even though this little presentation is under the general heading of missiles, structural dynamics problems apply to all flight vehicles whether it be airplanes or missiles. Therefore what I have to say should be more or less construed to apply to all types of flight vehicles.

TYPES OF MOTION INVOLVED IN STRUCTURAL DYNAMICS PROBLEMS

On the first chart we give as the definition of structural dynamics the fact that our structural deformation and motion vary rapidly with time. There are three types of motion involved in structural dynamics problems. The three categories are free, forced, and self-excited. I would like to say a few words about each of these categories to try to describe them a little more completely.

The "free vibration" category can be demonstrated with the aid of this simple winged model. If we plucked the wings and then let them vibrate by themselves undisturbed, then we have the phenomenon of free vibration. Now the methods of vibration may be very simple in form as is demonstrated by this simple model, or they may take on a very complex form, which is demonstrated by this cylinder. We have purposely built in waves here to demonstrate the vibratory pattern that is associated with this cylindrical-type surface. We should visualize the vibration as a breathing in and out of this pattern. These vibratory characteristics are basic ingredients to all structural dynamics problems. Therefore, much of our research in structural dynamics is devoted to determining means for assessing and determining what these structural vibration methods are.

Because the vehicle systems that we are dealing with now have become so diverse and complicated in form, we are trying to build up our laboratory facilities to cope more adequately with these vibration problems.

The second category of structural dynamics is that of forced motion. In this category our structure is acted upon by external forces. An airplane flying through gusty air is such an example where the turbulence of the air excites the wing into motion.

Another category is the problem of landing where the landing forces themselves excite the structure into motion. There are other problems of course of force vibration such as; the vibration of helicopter blades in the case of helicopters, the response of the aircraft when it is subjected to blast loads as might be encountered in the delivery of a nuclear weapon, or conversely, the use of a nuclear weapon to create a blast load to, say, destroy an enemy aircraft.

I will demonstrate one of the problems of forced vibration, that is, gust encounter, with the aid of a wind-tunnel model I have over at my right. There is one underlying factor about this category of forced motion and that is the basic philosophy that the structure must be designed to withstand all the loads that are imposed on it so that it will be structurally safe.

We pass on to the third category, that of self-excited motion. This is the most difficult of all three to comprehend. It is a situation where the airplane structure can withdraw energy from some source and cause a natural inherent stability of the structure. There are certain everyday examples that I am sure are familiar to you, such as the flutter of a flag, the singing of a TV antenna, or the oscillatory collapse of the Tacoma Narrows Bridge.

I can demonstrate the category of self-excited motion or as we refer to it "flutter" in the case of an aircraft by means of this wind-tunnel model over here in which we have mounted a small flexible aircraft. By means of this control I will cause this propeller to rotate which will draw air through the tunnel in this direction and thereby

simulate the flight of this airplane. I will gradually increase the air velocity until the model is caused to flutter.

Prior to the flutter phenomenon I will wiggle my hand in front of the tunnel to cause the air to be turbulent, and in so doing will demonstrate the phenomenon of forced motion due to turbulent air.

I think you can see from the violent oscillations that the airplane model underwent that we want to avoid situations like that, which is called flutter.

We can mention that this is the underlying philosophy of the third category. We want to design them out of the structure. They are like fatal diseases and we want to avoid them. Therefore, much of our research is devoted to understanding the causes and the cure of these self-excited-type motions. There is an instructive way of representing these various categories and that is afforded by the next chart. On this chart we show within the center here the flight system itself. It is composed of inertia or mass, a stiffness which we represent here by a spring, a propulsion system, and then some aerodynamic surface.

Surrounding the system we have the various environmental fields through which the system flies. By considering isolated parts of the diagram and their interaction we can demonstrate the various categories that we have just defined.

For example, if we consider just the mass and the stiffness, we have the category of free vibration. If we add to it the aerodynamic surface, and the flight media such as air, we would have the problem of flutter. Adding, say for example, the atmospheric disturbance such as turbulence, we would have the problem of forced motion, and so on around the chart.

It might be well now to look briefly into some of the current sources of structural dynamics problems.

SOURCES OF STRUCTURAL DYNAMICS PROBLEMS

In this chart we show the sources by referring to a launched supersonic or hypersonic vehicle in three different phases; the ascent, the orbiting, and the descent. We can regard the ordinate as the altitude. In the ascent phase, for example, there is a prelaunch problem such as Mr. Ames described previously in his talk of the smokestack oscillation of the missile in the prelaunch condition. At a little higher altitude we run into the gust problem.

A little higher on we run into severe acceleration loads or the noise problem due to the jet or rocket engine. I believe yesterday Mr. Hubbard gave a talk on the troubles that you can run into with jet noise in which structural failures of this type can be encountered in a matter of a very few minutes due to the intense action of the noise and jet forces. A little higher on the severe aerodynamic pressures may lead to self-excited motions.

Further around the chart we run into our various sources of structural dynamics problems. We can also demonstrate two of the problems that are indicated with the aid of this wind tunnel, and I would like to demonstrate this phenomenon of smokestack oscillation that Mr. Ames talked about.

We do this simply by removing our airplane model and inserting before the wind tunnel a model of a vehicle system that say is in the

state of launch or just prior to launch. The purpose of the wind tunnel here is to draw a wind over the model. At a certain velocity, the model should become slightly unstable; that is develop a self-excited-type motion. We will see if we can excite that into motion. I will gradually increase the speed. We notice that the model has undergone some vibratory type motion. In certain situations this can become very intense and actually cause the model to fail.

By means of this model, which represents a vehicle of the Dynasoar type mounted on a booster system, we will be able to demonstrate another type of instability that can be encountered under certain high-speed flight conditions. In this case the model has been made extremely flexible so that we can demonstrate the phenomenon with the aid of this low-speed wind tunnel which is capable of only drawing air through at a few feet per second instead of at hypersonic velocities. In this case, the model deforms and actually fails in a type of failure that is called divergence. Of course this is another type of instability that is to be avoided at all cost in the consideration of the flight of vehicles.

On this chart we will simply review some of the current structural dynamics problems; we have mentioned a few but by way of reemphasis we call attention to a specific few. We have shown here a certain type of vehicle. It could represent a rocket vehicle system or it might be representative in schematic form of a flexible airplane. We can run into the problem of wing flutter, panel flutter, and control flutter; we can run into the problem of divergence which we have just demonstrated.

Panels forming the exterior structure can be damaged by noise excitation. Or this excitation may come from the boundary layer or so-called aerodynamic noise. The body itself of the missile may be so flexible that we run into body deformation problems. This can couple with severe fuel sloshing problems within the missile. The engine or jet exhaust may be rough in its burning. The control which actuates the jet may interact with the body formations to lead to an instability called the control-structure interaction trouble. So this chart simply points up some of the current structural dynamics problems that we are doing research work on.

Now what has some of this research taught us in the field of structural dynamics? On this chart we summarize some of the recent NASA flutter studies.

FLUTTER STUDIES

We show here the type of vehicle that was tested and here the components on the particular vehicle. In this column we note that the vehicles are primarily of the airplane type whereas over here they are primarily of the missile type. The letters shown here are abbreviations. "HT" stands for the horizontal tail, "W" stands for the wing, "VT" stands for the vertical tail, "TEET" stands for a "T" tail. The letters shown in red indicate that flutter was actually encountered in the test or investigation of these vehicles. Those shown in black were found to be flutter free. You can note from this chart that over half of the vehicles tested had to be altered because of flutter troubles. On this chart we show an indication of the flutter and flight boundaries that have been found for certain wind tunnel studies. We

show a plot of the stiffness that is in the structure as a function of the speed, and let us focus attention first upon this red boundary. This is the boundary between the nonflutter region and the region of flutter. Thus if we are in this region, we will run into flutter trouble. It gives us an idea of how strong or how stiff we have to build the structure. For example, if we are flying at this speed, we must have a stiffness of this amount to prevent flutter.

However, if we increase the speed to this value, note that we have to increase the stiffness up to this value in order to avoid flutter. Now the actual shape of this boundary of course depends upon the particular type of wing or configuration that we are testing. Some wings follow the boundaries shown by the solid line, some the boundary shown by this red-dotted line. The hump here usually occurs, if it does, at a speed that is sonic speed, that is around 700 miles per hour.

I should mention in this connection that our research know-how and facilities are quite good into speeds up to around this region, that is just beyond the sonic speed. But we need to extend our research into the much higher speed ranges, that is the hypersonic range, because here our facilities tend to become inadequate.

In considering this type of flutter boundary, we can also judge it from the point of view of the performance capability of the aircraft. We can equally well consider this ordinate here to be altitude instead and thus if we look at it in terms of altitude versus speed, we can add to it a curve which refers to the performance capability of the airplane.

For example, a particular airplane may not be able to fly beyond this region; that is, at this altitude it cannot fly at this speed because it just does not have the power capabilities and so forth. However, if it did have the power capabilities or were able to penetrate this boundary, then you see even though it may have avoided flutter difficulty at this region, it is possible for it to again encounter flutter over at some higher speeds. So it is boundaries, of this type that we must define in order to be able to avoid here the problem of flutter.

On the next chart we show some additional results of flutter obtained in the study of the proper position on the wing to mount an engine, for example, in order to obtain the maximum flutter speed. This chart shows for example a sweptwing airplane, and studies were made

with an engine mounted at various locations to determine the associated flutter speed. The results indicate, for example, that an engine based anywhere along this line would lead to a flutter speed of 700 miles per hour. If the engine were placed anywhere along this line, the flutter speed would be 600, and so on around the chart.

Looking at these curves, we can see that obviously the best place to mount the engine would be in this region right here [indicating]. It is for the very reasons shown in this chart that airplanes such as the 707, DC–8, B–58, and so forth have their engines placed outward on the wing and so far in the forward direction of the wing.

DYNAMIC LOADS IN MISSILE DESIGN

On the last chart here we indicate some of the factors that are involved in designing a specific missile. We show loads that are due to static and dynamic sources. For example, we regard the chart in the following light. Along this direction we have position on the missile. In the vertical direction we have the bending moment that tends to break the missile in this manner. Thus, the bending moment due to winds that tends to break the missile at this position is this much.

The additive amount due to the engine forces is this much, and so on. Now the dynamic effects are due to gusts, the engine slamming hard over, aerodynamics or noise and so on and so forth.

We notice that the dynamic load sources here are by far predominant and exceed the static by several times. The outer curve shown in the diagram is the actual design strength that was supplied to the missile in its design. Now in some of the preliminary or early flyings of this particular missile certain failures were encountered. The fact that certain failures were encountered indicated that some of the information that went into the design was not sufficiently well known, and thus it indicates that more work is needed along these lines.

We can see that the field of structural dynamics is a curious one in that it represents the merging together of several technical areas, the structural areas and the aerodynamic areas.

As with most research problems, our attack on the problems is a multifaceted attack. We must employ wind tunnels, we must employ analytical means, use of models and so forth. I mentioned before that our coverage is quite fair in the low supersonic range and subsonic range, but our coverage in the hypersonic range is not as good as we would desire, and therefore we are making an effort to improve our coverage in this area. Thank you.

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STRUCTURAL DYNAMICS

STRUCTURAL DYNAMICS

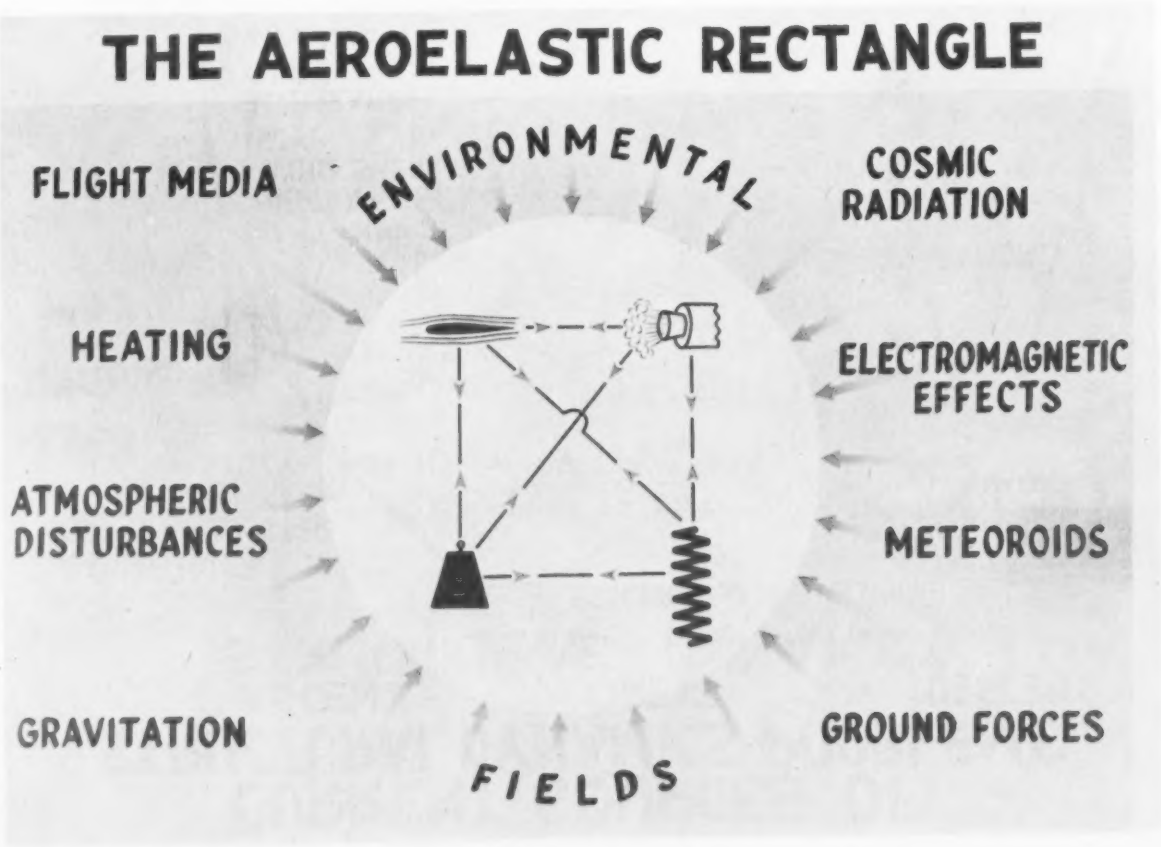
DEFINITION :

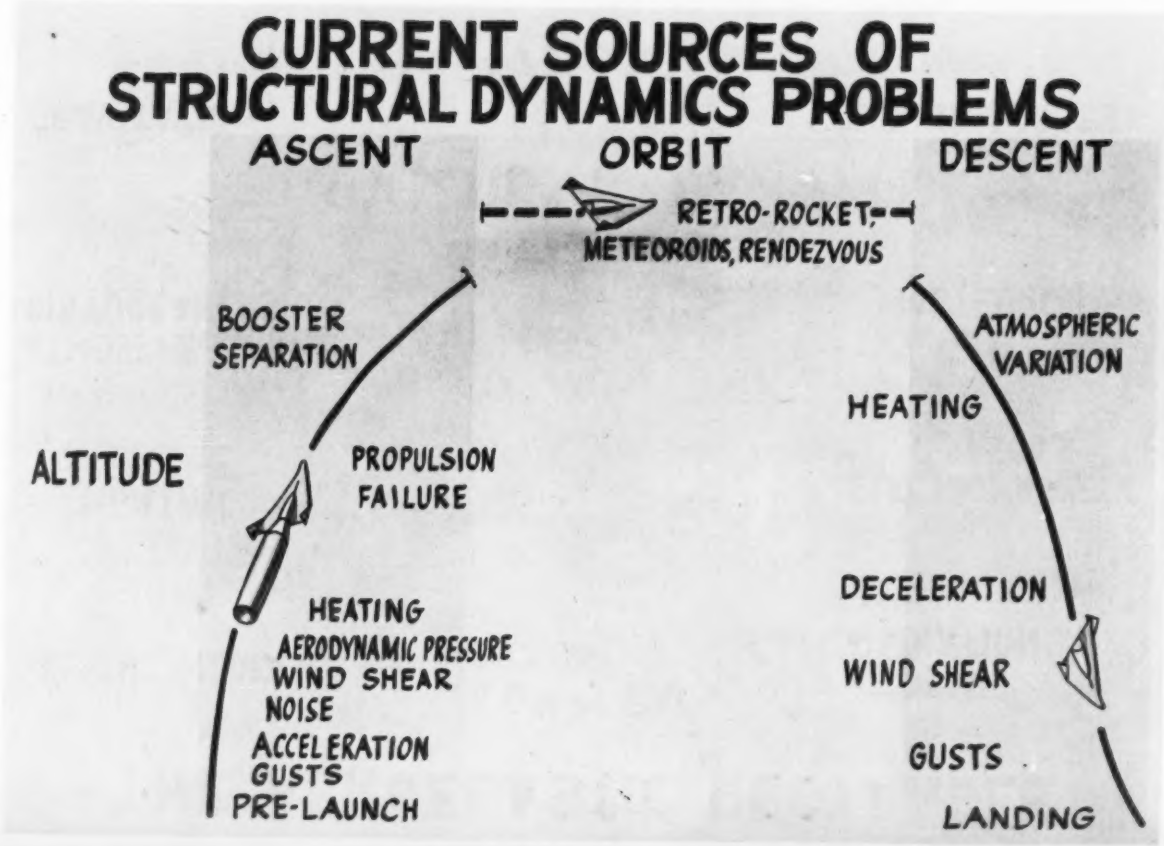
STRUCTURAL DEFORMATION AND MOTION VARY RAPIDLY WITH TIME.

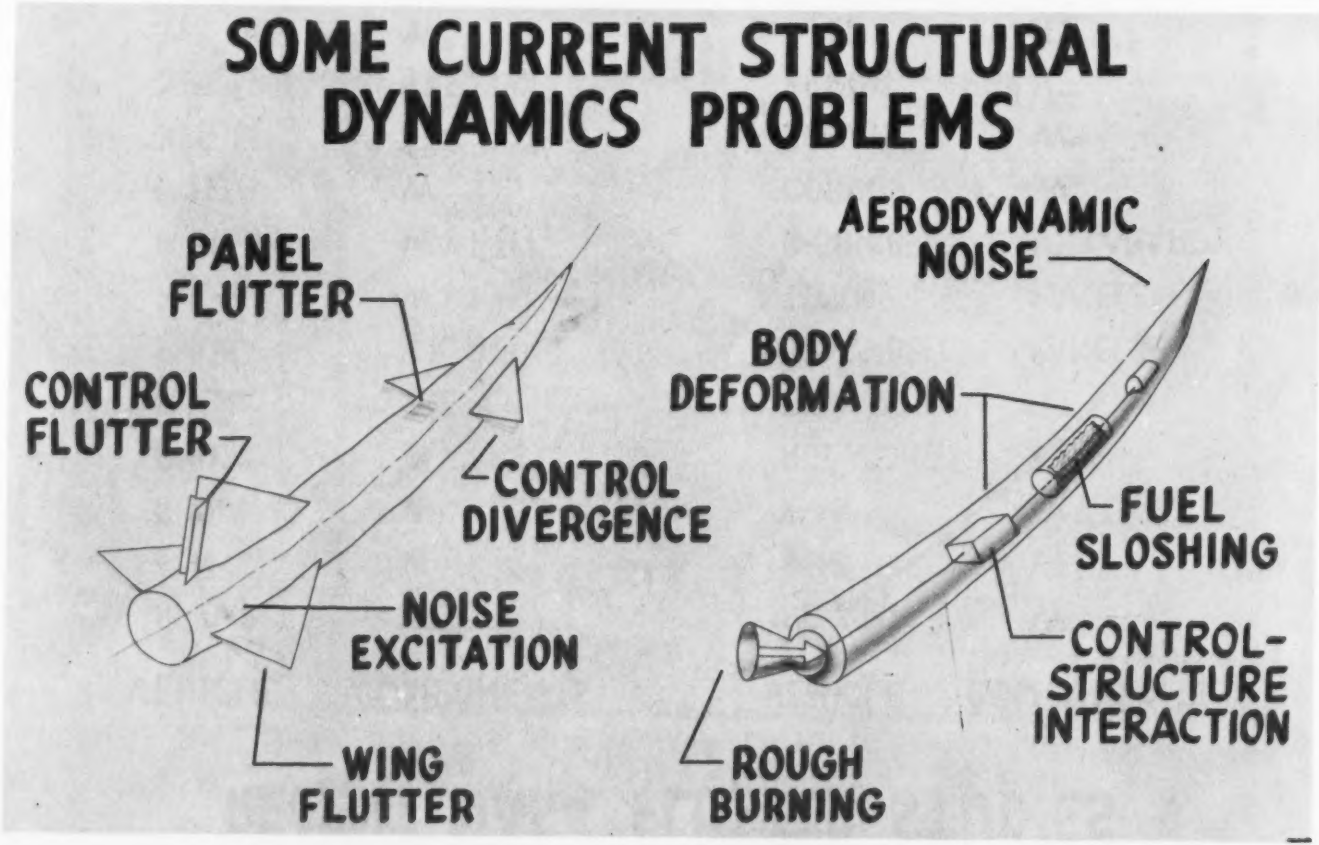
SCOPE :

MOTION IS

a) FREE
b) FORCED
c) SELF-EXCITED


THE AEROELASTIC RECTANGLE
ENVIRONMENTAL
FLIGHT MEDIA
COSMIC RADIATION
HEATING
ELECTROMAGNETIC EFFECTS
ATMOSPHERIC DISTURBANCES
METEOROIDS
GRAVITATION
GROUND FORCES
FIELDS


CURRENT SOURCES OF
STRUCTURAL DYNAMICS PROBLEMS
ASCENT
ORBIT
DESCENT
RETRO-ROCKET
METEOROIDS, RENDEZVOUS
BOOSTER
SEPARATION
ATMOSPHERIC
VARIATION
HEATING
ALTITUDE
PROPULSION
FAILURE
DECELERATION
HEATING
AERODYNAMIC PRESSURE
WIND SHEAR
NOISE
WIND SHEAR
ACCELERATION
GUSTS
GUSTS
PRE-LAUNCH
LANDING

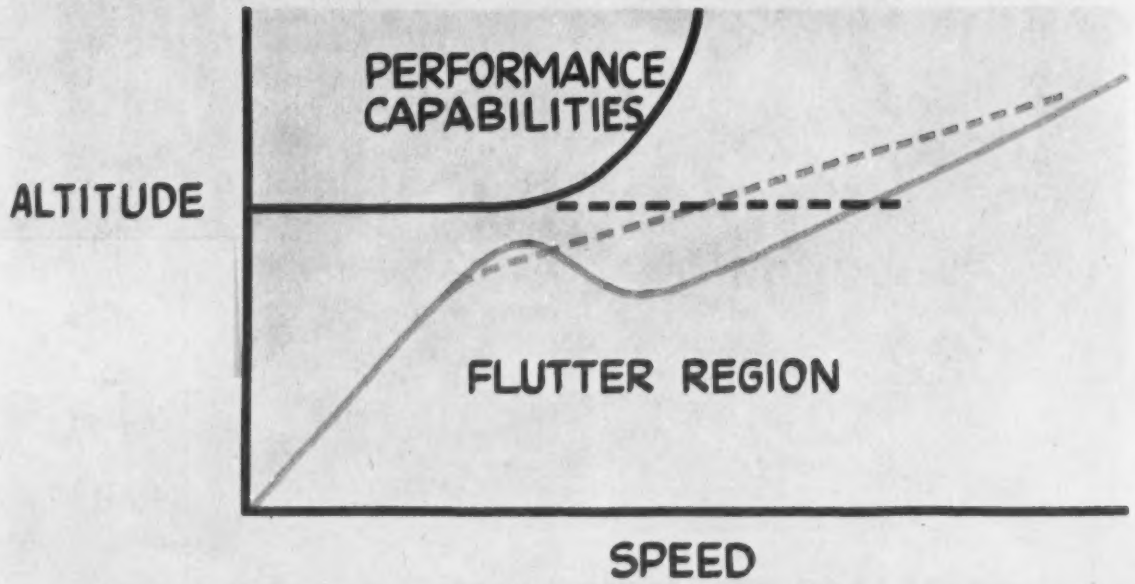

SOME CURRENT STRUCTURAL DYNAMICS PROBLEMS
PANEL FLUTTER
CONTROL FLUTTER
CONTROL DIVERGENCE
NOISE EXCITATION
WING FLUTTER
AERODYNAMIC NOISE
BODY DEFORMATION
FUEL SLOSHING
CONTROL-STRUCTURE INTERACTION
ROUGH BURNING

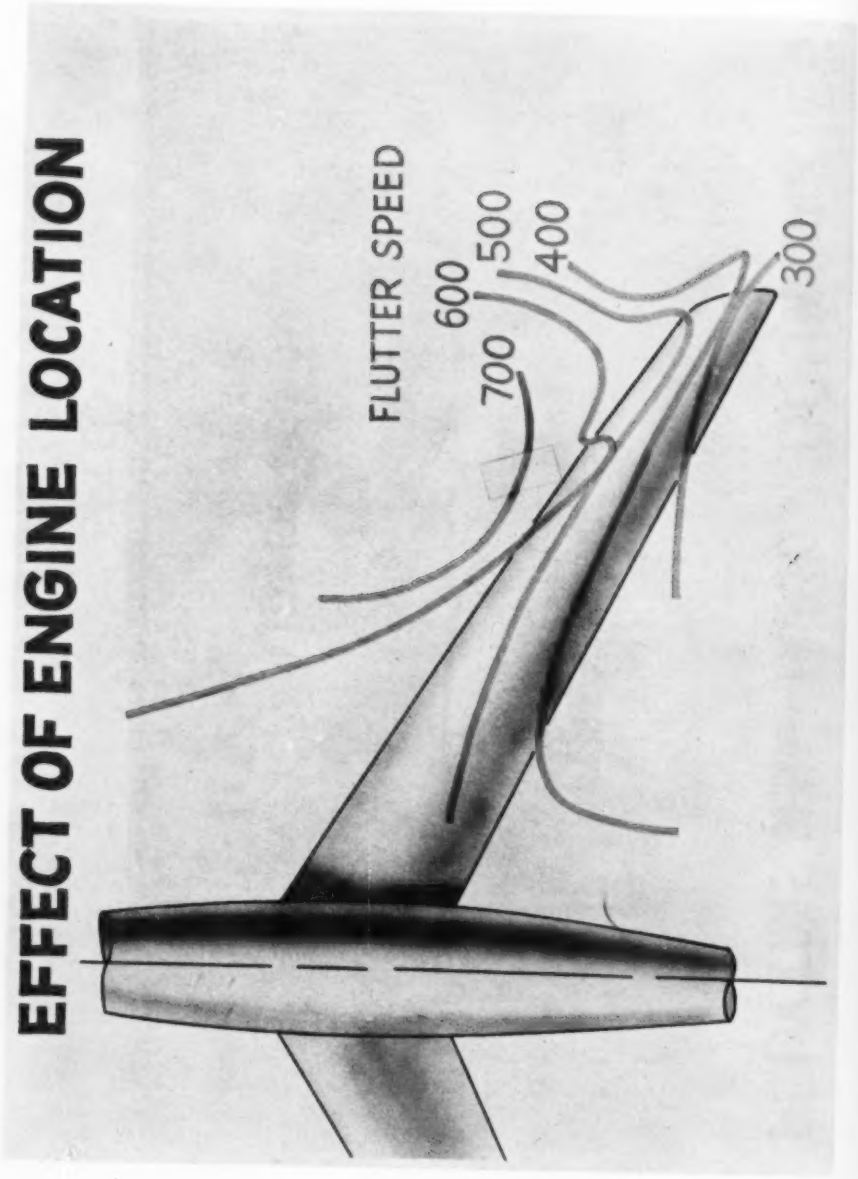
RECENT NASA FLUTTER STUDIES

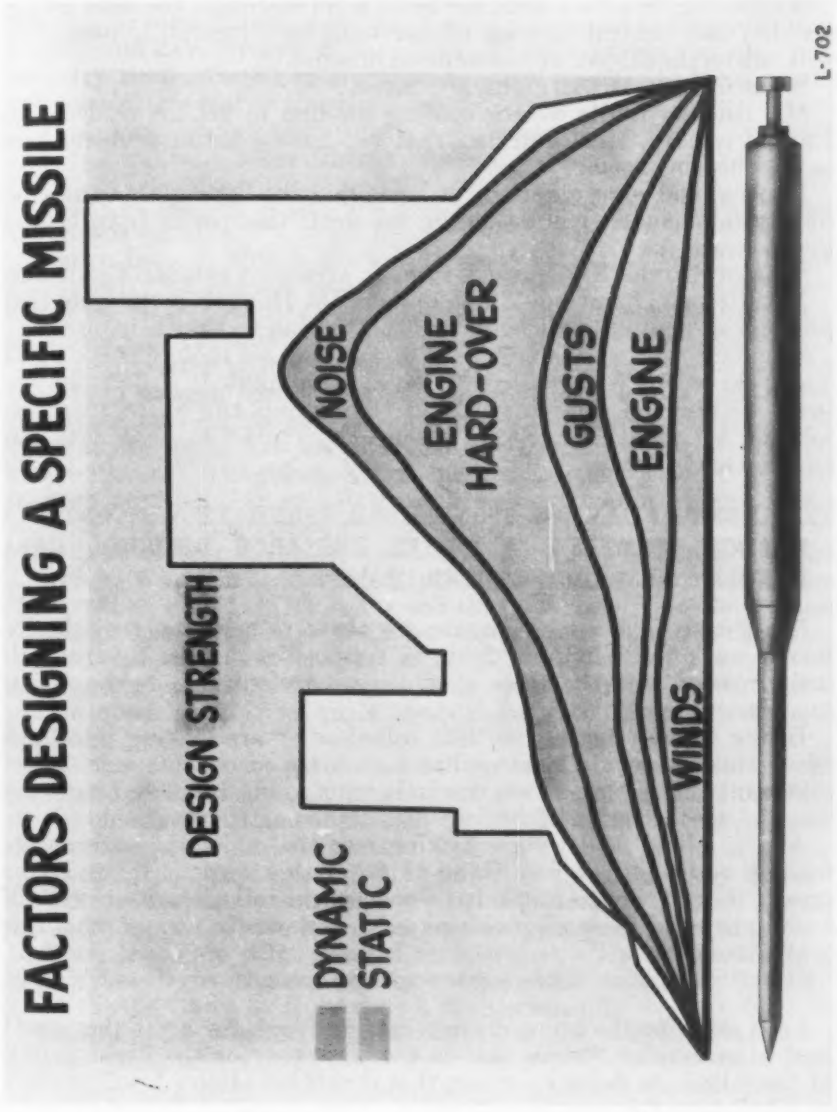
VEHICLE	COMPONENTS	VEHICLE	COMPONENTS
RF 84F	HT	WS 302A	W
F 94	W	X-1E	W
F 101A	W	X-15	W, VT, HT
F 103	W, VT, HT	REDSTONE	VT
F 104A	TEE T	BOMARC A	HT
F 105A	VT, HT	BRASS BELL	PANELS
F 105B	W, VT, HT	TITAN	PANELS
F 8U-3	W, VT, HT	B-58 (CBP)	VT, CANARD
F 11F-1	W	CORVUS	W
XP6 M	TEE T	BOMARC B	W
YP6 M	TEE, T	ASROC	VT
WS 110A	W	G-91	HT

WS 110A	W	G-91	HT

FLUTTER AND FLIGHT BOUNDARIES




EFFECT OF ENGINE LOCATION
FLUTTER SPEED
600
500
400
300
700


FACTORS DESIGNING A SPECIFIC MISSILE
DESIGN STRENGTH
DYNAMIC
STATIC
NOISE
ENGINE
HARD-OVER
GUSTS
ENGINE
WINDS
L-702

Senator STENNIS. You have given us a very fine demonstration here. I know little about the subject matter but you made it seem very real. If you will stay with us now, we may want to ask you some questions. Who do you have next, Mr. Rhode?

Mr. RHODE. We have next, sir, Mr. David G. Stone, the head of the stability and controls branch of our Langley Research Center, who will talk on the subject of interception missiles.

Senator STENNIS. All right, Mr. Stone.

Mr. RHODE. While we are waiting for him to get his models out, I might remark, Mr. Chairman, that you have a flutter problem here in your hearing room.

I notice, and some others of us have, that the little glass dangle on the crystal chandelier is waving in the draft that comes from behind the bookcase.

Senator SMITH. And it comes right on across my ear, Mr. Chairman.

Mr. RHODE. If you would like to have Dr. Houbolt investigate that problem and cure the difficulty, we will be glad to have him do so.

Senator STENNIS. We are going to wait and see though if it doesn't disappear when you gentlemen leave. [Laughter.] I had not noticed it until you came in with all your group and all of these exhibits. All right, Mr. Stone, we are very glad to have you, sir, and you may proceed.

TESTIMONY OF DAVID G. STONE, HEAD, STABILITY AND CONTROLS BRANCH, PILOTLESS AIRCRAFT RESEARCH DIVISION, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA.

Mr. STONE. The discussion you are about to hear concerns the research work the NASA is doing in support of defense against ballistic missiles, and the areas in which we are working now are outlined on this first chart.

In the defense against ballistic missiles, we are looking into antimissile missile requirements, what is required of the weapons system that is, missile configuration research, what kind of missile would you use, and the detection of bodies entering the earth's atmosphere.

And in allied field we are looking into the subject of antisatellite weapon system. The first thing to do in this work is to study the threat, that is, what are the basic concepts involved here, so we will know where the research problems exist, and get the idea of what this is all about.

ANTI-ICBM POINT DEFENSE

Let's examine the point defense case and look for areas that could lead to research. Shown here is the trajectory or the flight profile of the missile to defend a point, that is this blue line. I will explain in detail how the missile will work. First it will be launched vertically or near vertically for reasons of safety and reliability and guidance. So first there will be a booster that will lift the missile above the ground and boost it to a very high speed. Then the missile part of this vehicle will turn to get its payload lined up with the flight path. During this turn it also must accelerate so it can get to this point in time. Then from this point on it will coast into this position up here. It won't lose much velocity because we don't have much air up there any more.

Now one thing to note here is that this turn will be made mostly within the atmosphere. This means that we can use aerodynamic means to turn it. And so one of the problems right away is can you generate enough aerodynamic lift to turn this missile?

Can you use aerodynamic controls to tilt it so you can generate this lift to turn at high speeds? Can it withstand the aerodynamic heating and have structural integrity? The NASA has run some preliminary wind tunnel and other tests to give answers to these points, and some of this is shown on the next chart.

ANTIMISSILE CONFIGURATIONS

Shown at the top of this is a configuration for an antimissile missile that is suitable.

Shown here in blue is the booster to give it that initial altitude and velocity. This part here, which is really the missile part, I have called the steerable stage. It contains a warhead stage which breaks off and makes the final correction near the end of the mission.

Now this is the part here, the steerable stage, that has to generate the lift to make it turn. Preliminary wind tunnel tests have shown that these configurations down below will do this adequately. This chart shows configurations that have aerodynamic controls. In this case we have a configuration that has small wings with all movable controls near the rear, and in this one we have one in which the controls and the lifting devices are combined.

Both have their advantages and disadvantages. These two models I have here are the actual wind tunnel models tested at many times the speed of sound. This is the one that has the lifting devices and the controls all in one, and this has the controls near the rear.

Note that each is a little bit different. The controls on this one are lined up and from Mr. Ames' talk you just found out that those are no good. But if we place them in between like wings they fill the bill.

Now one thing that came out of these investigations was that this model, or this vehicle would proceed out of the atmosphere, the ability of the aerodynamic controls to tilt the missile would decrease faster than the aerodynamic lift required.

Therefore, it would not be able to tilt the missile to get the lift, so there is an aerodynamic control problem there. One way to get around that is of course to use reaction controls. Configurations that use those are demonstrated on this side. The reaction control is a rocket device that puts a force or a thrus normal to the flight path, that is shown by this exhaust out at the side.

That tilts the missile and gives the lift on the body; shown here is a body alone and a body with some wings to help the lift a little bit. Here is a body with a flared skirt that helps the stability.

All of these configurations would be capable of generating the force or G's to make this turn. Moreover, we are about now ready to flight test a model vehicle similar to this configuration to find out exactly how the aerodynamic controls lose effectiveness as it goes out through the atmosphere. This will give the designer some information on when to use aerodynamic controls or when not to use aerodynamic controls for his application. But all in all the initial tests

have shown that an antimissile for point defense can be designed, that is not large, enormously expensive or out of reason.

Another important thing that came out of the study of the threat was the time of flight for the missile. Of course, if you leave more time of flight for your antimissile, then this alleviates the performance requirements considerably. The velocity could be lower and you could maneuver easier at the lower velocity. So we might say then that the time of flight will design the antimissile missile. This requires us then to find out how we can detect incoming bodies easier and track them.

REENTRY DETECTION RESEARCH VEHICLE

Well, the NASA has started an investigation in this direction, and I would like to explain it now. There is a peculiar aerodynamics phenomenon that takes place upon reentry into the earth's atmosphere, and this is the phenomenon of ionization.

In other words, when a high speed body comes in it collides with the molecules of the air as it enters the rarified gas, which is the atmosphere. Electrically charged particles are given off and they stream out and behind in an aerodynamic fashion like an aerodynamic wake. This is usually called an ion sheet. This ion sheet will act like a billboard or a reflecting board for the radar and will enhance its radar signature echo. Now, theorists have indicated that this ionization is quite large, but in any event the theory that indicates this effect will be large is inadequate and therefore another experiment is in order to establish this.

On this next chart here we have a scheme for studying the detection of reentry bodies on an economic scale which is much less costly than using a full scale ICBM for this research. There is shown here a complete vehicle, the trajectory which is a profile of the flight plan and the velocity package. I will explain in detail how it works. This is an actual wind tunnel model to be sure it was stable when we flew the complete vehicle.

We have a green rocket motor here, an orange one, and a yellow one. These can be thought of only as elevator stages or altitude getters to get this final blue or velocity package up to a required altitude. By the way, this vehicle is about 60 feet long when all put together like this. This is shown on the chart, first the green motor fires, then the orange one, and then the yellow one. Then they drop off successively, of course. The velocity package is then coasting along by itself and when it gets to about 200 miles up, it goes to work. Within this velocity package are three more rocket motors. You can think of the velocity package as a flying launching tube if you wish, bottom of which is now open. When we reach the peak altitude here, the motors will fire in quick succession. We have a yellow motor, this orange one, and then this red one. This red motor is a special spherical motor specially designed and developed by NASA.

So when this spherical motor fires, it is the reentry object that we are going to look at and detect, and it is at ballistic missile speeds, that is in the order of 16,000 miles per hour from about 160 miles down to about 30 miles. We are going to be looking at this with radar

and optical means and every means that is available for detecting objects entering the earth's atmosphere.

I would like to repeat that this is a more economical scheme than using ballistic missiles. Also you will note that at that range here we are in close so that most of our instrumentation is here on the ground or in this locality.

The Defense Department and other agencies have shown a keen interest in this investigation, and we have welcomed their cooperation. In fact we have a cooperative program with the Lincoln Laboratory since they have most of the radars to look at it.

Another aspect that I would like to mention is this. We have launched the initial vehicle in this program and it was qualifiedly a success so now we are going ahead.

Mr. LEHRER. That is at Wallops Island?

Mr. STONE. Wallops Island. They are unguided and they are suited for our range.

WARHEAD-STAGE DYNAMICS

I will go over now another problem which we are studying, but as yet have no experimental phase. One of these is what goes on in the warhead-stage capability zone you saw on one of the other charts. In other words, the ground-based radar will guide this steerable stage up to where it is about in front of the incoming enemy ICBM. Well, at that time the warhead stage will separate from the missile, and it will have its own propulsion and its own guidance, that is a seeking system of some sort, and its job is to shove itself over in front of the ballistic missile, so that it is right exactly in front of this incoming path. There are two problems here.

One is that at the time that you decide to do this time is very short. Also seeker ranges are limited. That means then we have to put more propulsion into the steerable stage and better guidance into the steerable stage, which will run up the weight of the whole vehicle and then we might be defeated in that direction. So there are definite limitations that you can go either way. One of the important things here is we are back to a detection problem again. Most likely we are in space so there will not be any deterioration of this radio or optical propagation signal in space, so we are looking into an experiment now to look at a high-speed object in space while the looking device is also at high speed in space. So you could see we are looking into detection out in space. Also you can well appreciate that this could apply to rendezvousing with a satellite as well as the anti-ICBM problem.

Another thing that has to be done and is about to get underway is that it is possible that the warhead stage will be used at much lower altitudes. In that case this warhead stage will have to fly sideways, frontward, and backward, and the aerodynamics might upset it so we need wind tunnel tests to find out what are the upsetting forces here to take into consideration.

We are analyzing the problems concerned with area defense. This has shown so far that much more knowledge needs to be gained.

ANTISATELLITE MISSILE

The other allied field is of course with the antisatellite. The mission of the antisatellite weapon is to nullify the information that the enemy obtains with the reconnaissance satellite. I don't mean necessarily knock it down but to nullify it so no one can get the information off of it.

Well, in looking into this problem the detection items that are required are shown more or less on the bottom of the chart. In the scheme of things the satellite orbit might be as high as 400 miles, and it will come in here at which time the acquisition radar will acquire it. When the satellite gets here the launch of the antisatellite missile will be made from here. So again we can ask ourselves what kind of a vehicle will get up there. This does not come out to any extravagant thing.

What we found out so far in this analysis is, that problems with the antisatellite are similar to the anti-ICBM in that we need to study a staging of solid fuel rocket motors, detection in space, detection from the ground of things in space, because the atmosphere will act like a lens that we don't want to look through, and problems of guidance and aeroelasticity, so all these are things that we need to do for the antisatellie.

In conclusion, I would like to say that in doing this support research for the Defense Department we in the research centers are going to have to procure more facilities, more hardware, and more instrumentation and more rockets than we had in the past as the old NACA.

This concludes my discussion.

INTERCEPTOR MISSILES

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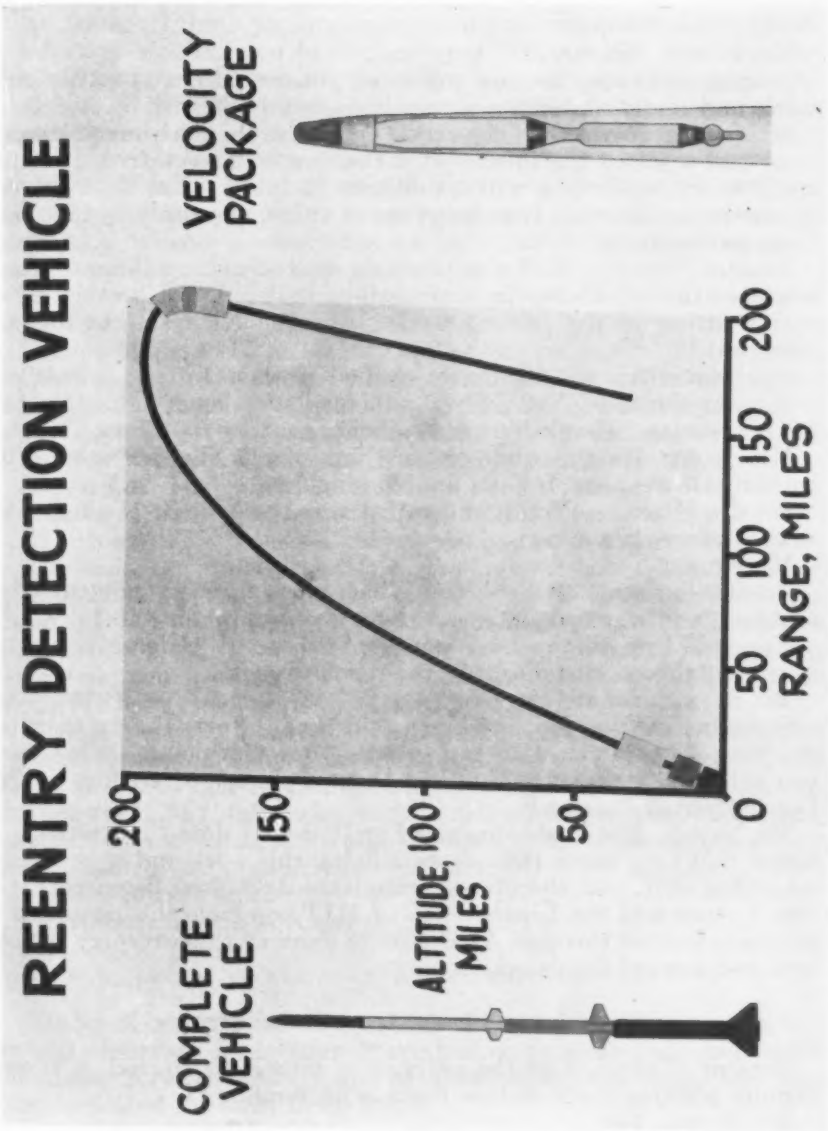
INTERCEPTOR MISSILES

DEFENSE AGAINST BALLISTIC MISSILES

ANTI-MISSILE MISSILE REQUIREMENTS
MISSILE CONFIGURATION RESEARCH
DETECTION RESEARCH

ANTI-SATELLITE WEAPON SYSTEM


REENTRY DETECTION VEHICLE
VELOCITY PACKAGE
COMPLETE VEHICLE
ALTITUDE, MILES
200
150
100
50
0
50
100
150
200
RANGE, MILES

Senator STENNIS. This is your last presentation?

Mr. RHODE. That is the concluding presentation, Mr. Chairman.

Senator STENNIS. May we ask Mr. Stone some questions at this point, sir? Mr. Stone, do you look upon this antisatellite problem as a major undertaking?

Mr. STONE. Yes, sir.

Senator STENNIS. To cope with that you would have to make new starts and really undertake a very extensive program?

Mr. STONE. New knowledge, yes. Of course though you can appreciate that a lot of the information that we could get from it could apply to rendezvousing with satellites. Actually what we are looking for is fundamental knowledge out in space, but applying it to this weapons system.

Senator STENNIS. Will you put your charts back up there to when you were talking about the antimissile missile. What do they come nearer fitting in the present use? Take the Nike system, for instance——

Mr. STONE. Are you familiar with the Nike-Zeus?

Senator STENNIS. Yes. I want to take that last. Let's take the Nike-Hercules. That is the more current one.

Mr. STONE. Well, I would rather think of the Nike-Hercules as an antiaircraft weapon. It has a limited range, sir.

Senator STENNIS. You would rather take the Nike-Zeus which is in more advanced planning?

Mr. STONE. Yes.

Senator STENNIS. All right. Where does it fit in now to your problems and what you have said here about developments?

You said something about the Department of Defense having a somewhat altered attitude, as I caught your words.

Mr. STONE. Not on this chart.

Senator STENNIS. No; later you said that. Now take up there on the Nike-Zeus, if you will, and give us your viewpoint. What were you referring to when you talked about a change of attitude in the Department of Defense?

Mr. STONE. Did I say change of attitude? I didn't mean that. I meant that they heard that we were doing this work and were keenly interested in it, and, therefore, through the Advanced Research Projects Agency and the Lincoln Lab of MIT, we have this cooperative program funded through ARPA to do more of these reentry vehicle tests and more of this detection work.

ANTIMISSILE MISSILE CONTROL SYSTEM

Senator MARTIN. Can the antimissile missile be steered in a very definite position itself so that there is no tumbling?

Mr. STONE. Yes.

Senator MARTIN. You can guide that?

Mr. STONE. Yes. This is one of the reasons that might cause them to use reaction controls all the way.

Senator MARTIN. You have fairly well-developed controls?

Mr. STONE. I would say that is a development problem now; not a research problem.

Senator MARTIN. I am just thinking of some of the questions that have come to my mind while you were giving this very fine discus-

sion—some of the things we have to imagine that you have under control.

And there is not anything that I have seen yet which indicates that one side is completely out in front on that.

Mr. STONE. I think you are right. But you have got to remember in a defensive weapon you have done your job, even if you have not fired a shot, if you have made the enemy go to a more elegant system; make him go to slender, sharp bodies that come in faster, or something like that, and he has got to do a better job. If you have forced him to do that, you have done part of your job.

Senator MARTIN. I do not want to ask too many questions here, but I do want to let my imagination range a bit. How can an adversary pinpoint a ballistic missile when we have just learned that the earth itself is a different shape than we thought it was?

Mr. STONE. Well, the guidance of ballistic missiles is a little bit out of my line.

Senator MARTIN. I was leading up to your testimony. If they have got that so accurately, then we have got to be accurate in meeting it.

Mr. STONE. The inertial guidance system lately has shown itself to be this accurate, if you can get the right velocity and angle.

Senator MARTIN. The inertial guidance system for——

Mr. STONE. The ballistic missile.

Senator MARTIN. The ballistic missile itself coming in.

Mr. STONE. This is one reason you want to make a more elegant system, to make the impact velocity of the ballistic missile much greater so that the winds that Mr. Allen talked about do not affect it when it comes in. You could run the impact velocity way up. Then this would avoid a lot of errors at the end due to the earth's atmosphere. Of course, you want to get your defensive missile to make him do that. We have to solve all these hard problems.

Senator MARTIN. I have no other questions. This is a little out of my own orbit, and I am a little handicapped on the questions I can ask—but I have seen most of these missiles in the making or in demonstration form. I think we have made marvelous progress, and I commend all of you for that. You have done a marvelous job in a very short time. Your presentation here is really quite advanced, and I appreciate it very much.

Mr. RHODE. Thank you, sir.

NASA COOPERATION WITH ARMED SERVICES

Senator MARTIN. I am very pleased with one thing if I can make this general observation—in your determination to make your work with the armed services entirely one of cooperation with them, and they have indicated the same thing to me.

I have been out in the field somewhat. The most encouraging thing in the whole picture is the desire of NASA and the armed services to work together; and, of course, to give you a proper range or laboratory without possible duplication—you need that cooperation. Just setting up testing sites for all of this so that you can really get a firsthand testing program going requires your working together. That spirit of cooperation is the most outstanding single factor, in my judgment.

Mr. STONE. I would like to say that all the rocket motors we use are obtained through the services.

Senator MARTIN. I cannot imagine how you are going to set up a very effective test in reality on some of these intercontinental ballistic missiles—effectiveness of the strike and effectiveness of the defense against them—but in your laboratories you are producing wonderful simulated systems or tests for it that we probably could not achieve in being in the field. I am through, Mr. Chairman.

COST OF ANTIMISSILE PROGRAM

Senator STENNIS. We have one or two more questions here.

One reference you made a while ago is this: You said that this antimissile-missile matter was not enormously expensive.

Mr. STONE. That is for the point defense. I mean we did not come out with an extravagant vehicle.

Senator STENNIS. You mean for the point defense.

Mr. STONE. Yes.

Senator STENNIS. That is small like the Nike-Hercules or the Nike-Zeus?

Mr. STONE. No. I am thinking of something just beyond the Nike-Zeus, but——

Senator STENNIS. You were talking about the experimental part in the first stages. When you go to operate them they are going to be very expensive, are they not?

Mr. STONE. In large numbers, yes. But part of that is out of our province, how many SAC bases you are going to defend, and so forth.

Mr. LEHRER. Now, may I move to clarify one other item. In terms of the antisatellite missile, a previous speaker mentioned that the orbit of the satellite could be altered by applying additional thrust or, as he called it, a kick in the apogee. Now, wouldn't such a maneuver defeat the ability of the antisatellite missiles being able to make contact?

Mr. STONE. I do not know which speaker said that, but that is going to take a lot of propulsion to change it in this time interval that I had on this chart. I am talking about when the thing is somewhere in between here. I think what he was talking about, in the propulsion, you would try to give it a kick in the apogee, so to speak, and by the time it got around another time there would be a change in it. And besides, the satellite he was talking about would be one that is out farther. It has a little longer path than this one.

So in this distance here, I do not think they are going to want to put all that power in to change that orbit in that distance.

Mr. LEHRER. One final item. Could you give us an estimate, when you say that the antimissile program would not be very expensive, what do you consider "not very expensive"? Are you talking in tens of millions of dollars, hundreds of millions, or billions of dollars?

Mr. STONE. When I said inexpensive, I meant each individual system by itself. Now, if you have to put thousands of them in to protect the country, why, then the expense is another item. What I mean is that an individual missile, an antimissile missile, will not, say, be the cost of one ICBM.

Mr. LEHRER. You are talking about what it would cost after it is fully developed, or——

Mr. STONE. Yes.

Mr. LEHRER. In other words, you are not including the billions of dollars that might be involved in actually developing the system.

Mr. STONE. That is right.

Mr. LEHRER. I think it is important that that distinction be made.

Mr. STONE. But I want to make the point that we are not shooting the missiles down with another missile which is as big as the one that we are shooting at.

Mr. LEHRER. That is all, Mr. Chairman.

Senator STENNIS. That was just a matter of the cost of your ammunition as against the problem.

Mr. STONE. This is a very important thing.

Senator STENNIS. All right; do you have something else, Mr. Rhode?

Mr. RHODE. This concludes our presentation, Mr. Chairman.

The only other thing I would care to say at this point is more or less a repetition of what I said yesterday afternoon. I wish to thank you most heartily on behalf of the NASA for your courtesy and patience in listening to us during such a long presentation, and to comment that you, sir, and the members of your committee who have listened to us have, in the judgment of those of us who have had the pleasure to appear here before you, displayed great dedication and fidelity to your own duties and responsibilities.

Senator STENNIS. We thank you very much, and I want to thank you on behalf of the entire subcommittee. If I may say this for the subcommittee, we wish to thank every individual who has appeared here, because you have really made a contribution not only to us but to the Congress and the people as a whole, including the entire Nation.

I know from the staff here, too, that Mr. James Gleason and Mr. Frank Marriott of NASA have been helpful in arranging all these hearings, and even though they did not appear as witnesses I wanted their names to be in the record with the thanks of the committee.

As chairman, for our committee I want to especially thank Mr. Max Lehrer for his valuable and able assistance in the preparation for these hearings and in the continuity of operations. His efforts and services have been outstanding in completing the picture so as to reflect all important activities which the committee might want to consider. We are deeply grateful for his tireless efforts and his splendid work.

Senator MARTIN. Mr. Chairman, I would like to observe that I have been attending hearings for some 20 years, and I have never attended a hearing which was as well run and covered so much important information in such a short space of time as these hearings.

Senator STENNIS. Thank you, Senator. I have a brief summary statement here.

This subcommittee has just concluded four days of intensive hearings covering the scientific and technical aspects of all the important projects in which the National Aeronautics and Space Administration plays a significant role.

This subcommittee has the responsibility for recommending appropriate legislative action on the NASA authorization request for fiscal year 1960. It was felt, however, that the specific programs proposed for the coming fiscal year could not be evaluated properly without first considering the space program in a broader perspec-

tive. Accordingly, consideration of the 1960 NASA authorization request was divided into two phases: (1) An exploration of the scientific and technical aspects of space and related programs; and (2) detailed examination of the specific programs proposed for fiscal year 1960.

The first phase has now been completed by the subcommittee. These hearings have produced a comprehensive picture of our current capabilities, of plans for the next decade, and an outline of how these plans are expected to be realized.

Some of the material presented to the subcommittee can only be described as astonishing. Mere recital of the general subjects covered—namely, research into atmospheres, space vehicle applications, advanced propulsion technology, missile and satellite support systems, manned space flight, advanced technology in guidance, atmospheres, space communications and materials, and problems involved in development and testing of aircraft, manned hypersonic vehicles and missiles—cannot portray the scope and importance of the information presented.

It is fair to say that the product of this first phase of our hearings essentially constitutes a primer of the space program, covering concisely but completely the planning for the space and related research programs for the next decade. As such, it should be of considerable interest and usefulness, not only to the members of this subcommittee and to the Congress, but to students and to the American people generally.

The subcommittee was tremendously impressed with the evident knowledge, enthusiasm, and dedication of the witnesses. For the most part, they are relatively young men, but the space age itself is only in its infancy. These men have demonstrated a grasp of their complicated subject matter that should be reassuring to the American people. I believe all America can be justly proud of these specialists and feel reassured that our vital space and scientific programs are in sound hands.

I want to add there that it takes a lot of courage and determination as well as foresight for men to launch into the unknown in these far-reaching programs. It is not vanity, but I am sure you cannot be accused of having an inferiority complex, either, to have the courage to launch into these fine programs, and I commend all of you.

Although space exploration and research in the field of missiles and space vehicles may appear to have little connection with our day-to-day life, the benefits of this basic research and applied technology will have a tremendous influence on our everyday way of life in the near future.

For example, a vast new knowledge of weather and climate is being gained through experiments. This will definitely have a bearing on the future of agriculture, both in America and throughout the world, and should provide sound fundamental knowledge for meeting the world's future need for food and fiber. A great deal of research is being conducted to discover properties of new and untried metals and chemicals. Amazing discoveries have been made. These will have a direct bearing on our standard of living in the near future. The transistor radio with its printed circuit is an example of this applied research.

Communications, worldwide, will be truly wonderful. Within the next few years it should be possible to receive radio and telephone messages and even live television programs originating anywhere in the world, through the use of communications satellites and the present limitations on these methods of communication would thereby be removed.

A large amount of the money spent on the space program therefore is actually being directed toward development of new products and techniques which will contribute greatly to peaceful enjoyment of life.

While the military phase of space, missile, and satellite research is of the utmost importance, as long as the Russians appear to be strong in the field of ballistic missiles, the long-run gains through the advancement of scientific knowledge, and with it the hope for a better peaceful world, will give us our lasting reward.

Mr. RHODE. Thank you very much, Senator Stennis.

Senator STENNIS. With the thanks of the committee, we will now take a recess, subject to the call of the Chair.

(Whereupon, at 4:45 p.m., the subcommittee recessed, subject to the call of the Chair.)

APPENDIX

United States and Russian Satellites, Lunar Probes and Space Probes 1957, 1958, and 1959

(Official statistics prepared by the National Aeronautics and Space Administration [1])

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Sputnik I, Russia: Satellite (sphere). Estimate of total payload weight in orbit: About 4 tons (unofficial). Scientific instrumentation in payload: 184 lb.	Oct. 4, 1957, to Jan. 4, 1958.	Not disclosed	Dimensions: 22.8 in. in diameter. Experiments: Internal temperatures, pressures, and other data. Shell composition: aluminum alloys. Antennas: 4 spring-loaded whip antennas, 4 ft 10.5 in. to 9 ft. 6 in. Transmitters: (*a*) 20.005 mc.; (*b*) 40.002 mc. Power supply: Chemical batteries. Transmitter lifetime: (*a*) and (*b*) stopped Oct. 27, 1957.	Period: 96.17 minutes; speed (perigee): 18,000 m.p.h.; speed (apogee): 16,200 m.p.h. Inclination to Equator: 65°.	142	588
Sputnik II, Russia: Satellite (complex). Estimate of total payload weight in orbit: About 4 tons (unofficial). Scientific instrumentation in payload: 1,120 lb.	Nov. 3, 1957 to Apr. 14, 1958.	do	Dimensions: Not disclosed. Experiments: Cosmic rays; solar ultraviolet and X-radiation; test animal "Laika" (dog); temperatures; pressures. Shell composition: Aluminum alloys. Antennas: Not disclosed. Transmitters: (*a*) 20.005 mc.; (*b*) 40.002 mc. Power supply: Chemical batteries. Transmitter lifetime: (*a*) and (*b*) stopped Nov. 10, 1957.	The available acceleration of this satellite led to the discovery of significant solar influence on upper atmosphere densities. Period: 103.70 minutes; speed (perigee): 18,000 m.p.h.; speed (apogee): 15,000 m.p.h. Inclination to Equator: 65°.	140	1,038
Vanguard (test vehicle 3) United States: Satellite (sphere). Scientific payload and total weight in flight: 3.4 lb.	Dec. 6, 1957 to 0.	U.S. Navy test vehicle 3. Stages: 3—1st: liquid; 2d: liquid; 3d: solid. Gross takeoff weight: 22,600 lbs. Height: 72 ft. Diameter (base): 45 in.	Dimensions: 6 in. in diameter. Experiments: Micrometeor impact and geodetic measurements. Shell composition: Magnesium, aluminum, silicon monoxide. Antennas: 1 turnstile antenna; 1 dipole antenna with total of 6 12-in. rod elements. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) mercury batteries; (*b*) 6 groups of solar converters.	Vehicle lost thrust after 2 seconds and was consumed in flames. Cause: malfunction in 1st stage.	0	0
Explorer I, United States: Satellite (cylinder). Total payload weight in orbit, 30.8 lbs. Scientific instrumentation in payload, 18.13 lbs.	Jan. 31, 1958 (estimated lifetime: 3 to 5 yr.).	U.S. Army Jupiter C: Stages: 4—1st, elongated Redstone (liquid); 2d, scaled-down Sergeant rockets (solid); 3d, scaled-down Sergeant rockets (solid); 4th, single scaled-down Sergeant (solid). Height: 68.6 ft.	Dimensions: 80 in. long; 6 in. in diameter. Experiments: cosmic rays; micrometeorites: (*a*) microphone; (*b*) gages; temperatures: internal, rear skin, front skin, and nose cone. Shell composition: Steel with 8 aluminum oxide strips. Antennas: 1 turnstile antenna with 4 whip elements each 22.5 in. long; 1 dipole antenna using skin of satellite itself. Transmitters: (*a*) 108 mc. at 10 mw. and (*b*) 108.03 mc. at 60 mw. Power supply: Mercury batteries. Transmitter lifetime: (*a*) Stopped May 23, 1958; (*b*) stopped Feb. 11, 1958; began again Feb. 24; stopped finally Feb. 28, 1958.	Explorer I is credited with what is probably the most important satellite discovery of the International Geophysical Year; i.e., a radiation belt around the Earth identified by Dr. James A. Van Allen, head of the University of Iowa Physics Department. A 2d belt was discovered later by Pioneer III. Period: 114.8 min. Inclination to Equator: 33.34°.	224	1,573
Vanguard: (test vehicle 3 backup) United States: same as TV 3.	Feb. 5, 1958 to 0.	Same as Vanguard test vehicle 3.	Same as Vanguard test vehicle 3	After a successful liftoff and 57 sec. of flight, a connection between units of 1st stage control system failed to function. At an altitude of 20,000 ft., the rocket veered off course with such force that it snapped apart and fell.	0	0

See footnotes at end of table.

United States and Russian Satellites, Lunar Probes and Space Probes 1957, 1958, and 1959—Continued

(Official statistics prepared by the National Aeronautics and Space Administration)[1]—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Explorer II, United States: Satellite (cylinder). Total payload weight in orbit, 31.50 lbs. Scientific instrumentation payload, 18.83 lbs.	Mar. 5, 1958 to 0	U.S. Army Jupiter C (same as Explorer I).	Dimensions: 80 in. long; 6 in. in diameter. Experiments: Cosmic ray count; micrometeor impact count; cosmic ray measurement. Shell composition: No. 410 stainless steel. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (*a*) 108.03 mc. at 60 mw.; (*b*) 108.00 mc. at 10 mw. Power supply: Mercury batteries.	Last stage failed to ignite. Vehicle did not achieve orbit. Flight time: 823 sec.	0	0
Vanguard I, United States: Satellite (sphere). Scientific payload and total weight in orbit, 3.25 lbs. (Also in orbit, 50-lb. 3d stage rocket casing.)	Mar. 17, 1958 (estimated 200 yrs. to 1,000 yrs.).	Same as test vehicle 3.	Dimensions: 6.4 in. in diameter. Experiments: Temperatures and geodetic measurements. Shell composition: Aluminum. Antennas: one turnstile antenna and one dipole antenna with total of six 12-in. rod elements. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) Mercury batteries; (*b*) 6 groups of solar converters. Transmitter lifetime: (*a*) Ceased operating Apr. 5, 1958; (*b*) will operate indefinitely.	The solar-powered radio should transmit indefinitely. The Army Map Service has been making electronic observations of the satellite from Pacific islands to pinpoint their location more exactly. The satellite is also being used for more exact determination of the Earth's shape.	409	2,453
Explorer III, United States: Satellite (cylinder). Total payload weight in orbit, 31 lbs. Scientific instrumentation payload, 18.56 lbs.	Mar. 26, 1958 (June 27, 1958).	U.S. Army Jupiter C (same as Explorers I and II).	Dimensions: 80 in. long; 6 in. in diameter. Experiments: Cosmic rays with tape-recorder feature; micrometeor gages; temperatures, (*a*) skin and (*b*) internal. Shell composition: Steel with 8 aluminum oxide strips. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 60 mw. Power supply: Mercury batteries. Transmitter lifetime: (*a*) Telemetering and beacon signal stopped May 10, 1958; beacon transmitted again May 15-June 16; (*b*) first stopped May 14; responded erratically May 22-June 5, 1958.	Explorer yielded valuable data on the radiation belt discovered by Explorer I as well as data on micrometeor impacts (density of cosmic dust) and internal and external temperature of the satellite. Period: 115.87 min. Inclination: 33.4°.	121	1,746
Vanguard (test vehicle 5): Satellite (sphere). Scientific payload and total weight in orbit, 21.5 lbs.	Apr. 28, 1958–0	Same as TV 3	Dimensions: 20 in. in diameter. Experiments: Measure X-radiation from the sun. Shell composition: Highly polished silicon-monoxide-coated magnesium. Antennas: 4 metal rods. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) Mercury batteries; (*b*) 6 groups of solar converters.	2 minor components (electric relays) malfunctioned and failed to signal the 3d stage to fire. 2d and 3d stages impacted 1,500 miles from launch site.	0	0
Sputnik III, Russia: Satellite (conical). Total payload	May 15, 1958; estimated life-	Not disclosed	Dimensions: 11 ft., 9 in. long; 5 ft. 8 in. wide at base. Experiments: Atmospheric pressure and compo-	Period: 106 min.; speed (perigee): 18,837; speed (apogee): 14,637.	135	1,167

Sputnik III, Russia: Satellite (conical). Total payload weight in orbit: About 7,000 lb. (unofficial). Scientific instrumentation payload, 2,925 lb.	May 15, 1958; estimated lifetime: 15 months.	Not disclosed	Dimensions: 11 ft., 9 in. long; 5 ft. 8 in. wide at base. Experiments: Atmospheric pressure and composition; concentration of positive ions; satellite's electrical charge and tension of earth electrostatic field; tension of earth's magnetic field; intensity of sun's corpuscular radiation; composition and variations of primary cosmic radiation; distribution of photons and heavy nuclei in cosmic rays; micrometeors; temperature measurements. Shell composition: Aluminum alloys. Antennas: Folded dipole antennas and trailing rod antennas. Transmitters: (*a*) 20.005 mc. (transmission at 40.01 mc. is harmonic of 1st) Power supply: (*a*) chemical batteries; (*b*) solar batteries.	Period: 106 min.; speed (perigee): 18,837; speed (apogee): 14,637. Inclination to Equator: 65.3°.	135	1, 167
Vanguard, satellite launching vehicle 1 (no name), United States: Satellite (sphere). Scientific payload and total weight in orbit: 21.5 lb.	May 27, 1958–60.	Same as TV 3	Dimensions: 20 in. in diameter. Experiments: Solar Lyman-Alpha radiation and space environment. Shell composition: Highly polished silicon monoxide coated magnesium sphere. Antennas: 4 metal rods. Transmitter: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) Mercury batteries; (*b*) 6 groups of solar converters. Transmitter lifetime: same as flight time; i.e. 20 min.	Second stage engine did not cut off properly, causing vehicle to fly with nose upward rather than parallel to earth. Caused 3d stage to fly in high arc-like trajectory. 3d stage of satellite reached peak altitude of 2,200 miles and traveled 7,500 miles from Cape Canaveral, landing near east coast of Union of South Africa. Flight time: 20 min.	0	0
Vanguard (SLV 2) (no name) United States: Satellite (sphere). Scientific instrumentation in payload and total weight in orbit: 21.5 lb.	June 26, 1958–60.	do	Dimensions: 20 in. in diameter. Experiments: Measurements of X-radiation from the sun. Shell composition: Highly polished silicon monoxide magnesium sphere. Antennas: 4 metal rods. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) mercury batteries; (*b*) 6 groups of solar converters.	Second stage motor cut off prematurely due to low chamber pressure and terminated the flight.	0	0
Explorer IV, United States: Satellite (cylinder). Total payload weight in orbit: 38.4 lb. Scientific instrumentation in payload: 25.8 lb.	July 26, 1958; Expected lifetime: about 1 year.	Same as Explorer I	Dimensions: 80.39 in. long; 6.25 in. in diameter. Experiments: 2 Geiger-Mueller counters and 2 scintillation counters to measure corpuscular radiation at several intensity levels. The subcarrier oscillator was calibrated to give internal temperature measurements. Shell composition: stainless steel. Antennas: 2 dipole antennas using the skin of the satellite itself. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 24 mw. (each transmitter broadcasts all 5 channels of information simultaneously and continuously. The 1st transmitter is primarily for tracking.) Power supply: Mercury batteries. Transmitters lifetime: Sept. 3, 1958: Telemetry on channels 2 and 5 cease. Sept. 9, 1958: 108.00 mc. transmitter ceased operation Sept. 19, 1958: Last intelligible telemetry on 108.03 mc. transmitters. Oct. 6, 1958: 108.03 mc. transmitter ceased.	Same as Explorer I and III, i.e. valuable data on radiation belts, etc. Period: 110.27 minutes. Inclination to Equator: 50.29°.	163	1, 380

See footnotes at end of table.

United States and Russian Satellites, Lunar Probes and Space Probes, 1957, 1958, and 1959—Continued

(Official statistics prepared by the National Aeronautics and Space Administration)[1]—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee (miles)
No name, United States: Lunar probe (toroidal). Total payload weight in flight, including 4th stage shell: 83.8 lb. Scientific instrumentation in payload: 25 lb.	Aug. 17, 1958–60	Thor-Able I Stages: 4. 1st: Thor (liquid); 2d: Modified Vanguard. 2d stage (liquid); 3d: X2 Allegany Ballistic Laboratory (solid); 4th: Thiokol (solid). Gross take-off weight: 112,000 lb.; height: 88.1 ft.	Dimensions: 29 in. in diameter; 30 in. long. Experiments: Measurements of radiation in space; magnetic fields of Earth and Moon; density of micrometeoric matter; internal temperatures; electronic scanner. Shell composition: Fiberglass. Antennas: Two 12-inch whips. Transmitters: (*a*) 108.6 mc. at 300 mw. (telemetry and doppler command); (*b*) 108.09 mc. at 1 watt. Power supply: Mercury batteries. Transmitter lifetime: 10 days.	Engine failure in 1st stage caused vehicle blow up 77 seconds after launch.	(3)	(3)
Explorer V, United States: Satellite (cylinder). Total payload weight in orbit: 38.43 lb. Scientific instrumentation in payload: 25.8 lb.	Aug. 24, 1958–60	Jupiter C	Dimensions: 80 in. long, 6 in. in diameter. Experiments: measurement of corpuscular radiation at several intensity levels. Shell composition: No. 410 stainless steel. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (*a*) 108.03 mc. at 30 mw.; (*b*) 108.00 mc. at 10 mw. Power supply: Mercury batteries.	Successful launching. All stages fired. Orbit was not achieved because of a collision between parts of the booster and the instrument compartment which carried the 3 high-speed stages. The high-speed stages fired in wrong direction. Flight time: 659 seconds.	0	0
Vanguard (SLV 3) United States: Satellite (sphere). Scientific instrumentation in payload and total weight, 21.5 lb.	Sept. 26, 1958–0	Same as TV 3	Dimensions: 20 in. in diameter. Experiments: 2 infrared photocells to scan earth's cloud cover. Shell composition: Magnesium. Antennas: 1 turnstile antenna with 4 30-in. spring-loaded rod elements. Transmitters: 108.00 mc. at 10 mw. and 108.03 mc. at 1 watt. Power supply: Mercury batteries.	2d stage failed to give minimal performance, which caused vehicle to fall back into atmosphere and burn up. It is believed to have made 1 complete orbit of Earth before falling back and burning up over central Africa.	0	0
Pioneer I, United States: Lunar probe (torodial). Total weight in flight, 84.4 lb., including 43.7 lb. of verniers and retrorockets. Scientific instrumentation in payload, 39 lb.	Oct. 11–12, 1958, or 43 hrs. 17½ min.	Thor-Able I	Dimensions: 29 in. in diameter, 30 in. long. Experiments: Measurements of radiation in space; magnetic fields of Earth and Moon; density of micrometeor matter; internal temperatures; electronic scanner. Shell composition: Fiberglas. Antennas: 2 12-in. whips. Transmitter: (*a*) 108.06 mc. at 300 mw. (telemetry and Doppler command); (*b*) 108.06 mc. at 1 watt (controls). Power supply: Mercury batteries. Transmitter lifetime: 10 days.	Reentered atmosphere over South Pacific Oct. 12, 1958. (*a*) Determination of radial extent of radiation band. First observation that radiation is a band. (*b*) Mapped total ionizing flux. (*c*) 1st observation of hydromagnetic oscillations of magnetic field of Earth. (*d*) Discovered departure of magnetic field from theoretical prediction. (*e*) 1st determination of the density of micrometeors in interplanetary space. (*f*) 1st measurements of the interplanetary magnetic field.	(4)	(4)
Beacon, United States: Inflatable satellite (sphere). Pay-	Oct. 23, 1958–0	Jupiter C	Dimensions: 50 in. long, in. in diameter; contained the foiled sphere, tracking transmitter,	Part of the cluster, including payload, separated from the booster	0	0

			space. (*f*) 1st measurements of the interplanetary magnetic field.			
Beacon, United States: Inflatable satellite (sphere). Payload case, 18.3 lb.; rocket case, 11.27 lb.; total, 31.5 lb. Weight of inflatable satellite when free of payload case, 9.26 lb.	Oct. 23, 1958–0...	Jupiter C.....	Dimensions: 50 in. long, in. in diameter; contained the foiled sphere, tracking transmitter, kick motor, and pressurized bottle. Experiments: Ejection of sphere from payload package; sphere itself would be used to study atmospheric density at various levels during lifetime of about 2 weeks. Shell composition: Mylar polyester film and microthin aluminum foil. Transmitters: None.	Part of the cluster, including payload, separated from the booster prior to booster burnout. Flight time of payload, 424 sec. Flight time of booster, 526 sec.	0	0
Pioneer II, United States: Lunar probe (toroidal). Total weight in flight, 86.4 lb. Scientific payload, 34.3 lb.	Nov. 8, 1958, 42.4 min.	Thor-Able I.....	Dimensions: 29 in. in diameter; 30 in. long. Experiments: Total ionizing radiation; cosmic ray flux; magnetic fields of Earth and Moon; density of micrometeoric matter; internal temperatures; electronic scanner. Shell composition: Fiberglas. Antennas: 2 12-in. whips. Transmitters: 108.06 mc. at 300 mw. (telemetry and Doppler command) and 108.09 mc. at 100 mw. (telemetry). Power supply: Mercury batteries. Transmitter lifetime: 10 days.	3d stage failed to ignite. Reentered atmosphere 28.7° N., 1.9° E. (*a*) Evidence that equatorial region about Earth has higher flux and higher energy radiation than previously considered. (*b*) Suggestion that micrometeor density is higher around Earth than in space.	(5)	(5)
Pioneer III, United States: Space probe (conical). Total weight in flight and scientific payload, 12.95 lb.	Dec. 6–7, 1958, or 38 hr., 6 min. after launch.	Juno II stages (4): 1st, Jupiter (liquid); 2d, 11 clustered Sergeants (solid); 3d, 3 clustered Sergeants (solid). Gross take-off weight, 121,000 lb.	Dimensions: 23 in. long; 10 in. maximum diameter. Experiments: Measurement of radiation in space. Shell composition: Gold-washed Fiberglas. Antenna: Cone itself serves as antenna; gold is conductor. Transmitters: 960.05 mc. at 180 mw. Power supply: Mercury batteries. Transmitter lifetime: 90 hr.	Discovered 2d radiation belt around Earth. Reentered atmosphere over French Equatorial Africa on Dec. 7, 1958. Designed velocity, 24,897 m.p.h. Attained velocity, about 24,000 m.p.h.	(6)	(6)
Project Score (Atlas), United States: Satellite. Total weight in orbit, 8,750 lb. Scientific instrumentation in payload, 150 lb.	Dec. 18, 1958–Jan. 21, 1959.	WS107A–1 (Atlas): Powerplant, 2 boosters (approximately 150,000 lb. each) and 1 sustainer engine (all liquid) plus 2 verniers. Gross take-off weight, about 244,000 lb. Height, 85 ft. Diameter, 10 ft.	Dimensions: 85 ft. long, 10 ft. in diameter. Experiments: Twin packages of radio transmitting, recording, and receiving apparatus, each weighing 35 lb. Other components included a battery, a voltage converter, radio beacon, and a control unit. Shell composition: Stainless steel. Antennas: Slot-type, flush with body of the Atlas. Transmitters: FM, 132.435 mc. and 132.905 mc. Minitrack signals: 107.97 mc. and 107.94 mc. Power supply: Mercury batteries. Transmitter lifetime: 12 days.	1st time a human voice has been beamed from outer space. Message from President Eisenhower recorded and transmitted. Satellite accepted and relayed messages from ground stations in Texas, Arizona, and Georgia. It came down in vicinity of Midway Island in Pacific Ocean. Initial period, 101.46 min. Inclination, 32.3°.	110	920
Lunik or Mechta (Dream), Russia: Space probe (sphere). Total weight in flight, 3,245 lb.[7]	Jan. 2, 1959 (believed to be in orbit around Sun).	T–3 stages: 3. Speculated total thrusts, 580,000 lb. Height, 110 ft.	Dimensions: Not disclosed. Experiments: Instruments to measure temperature and pressure inside vehicle; instruments to study gas components of interplanetary matter and corpuscular radiation of the Sun; magnetic fields of Earth Moon; meteoric particles in space; heavy nuclei in primary cosmic radiation and other properties of cosmic rays. Shell composition: Pentagonal strips of stainless steel made of 2 hermetically sealed shells of aluminum-magnesium alloy. Antennas: Not disclosed. Transmitters: 3. (*a*) 19.997 mc. and 19.995 mc. signals of 1.6-sec. duration; (*b*) 19.993 mc. signals of 50.9 sec. duration; (*c*) 183.6 mc.	In orbit around Sun on 15-mo. cycle.	.....	.....

See footnotes at end of table.

United States and Russian Satellites, Lunar Probes and Space Probes 1957, 1958, and 1959—Continued

(Official statistics prepared by the National Aeronautics and Space Administration)[1]—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Vanguard II, United States: (Sphere). Total weight in orbit and scientific instrumentation, 20.74 lb.	Feb. 17, 1959. Expected lifetime, 10 yr. or more.	Vanguard rocket (same as test vehicle 3).	Dimensions: 20 in. in diameter. Experiments: Cloud cover. Shell composition: Highly polished silicon monoxide coated magnesium. Antennas: 4 metal rods. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 80 mw. triggered from ground. Power supply: Mercury batteries. Transmitter lifetime: (*a*) 23 days; (*b*) 27 days. Satellite contained 2 photocells designed to produce crude images of cloud cover for 2-week period.	Period: 125.85 min. Inclination to Equator: 32.88°. In general the satellite and its instrumentation functioned as planned. However, interpretation of data has been difficult because satellite developed a wobbling (precessing) motion.	347	2,064
Pioneer IV, United States: (Conical). Total weight in flight and scientific instrumentation, 13.40 lb.	Mar. 3, 1959. In orbit around sun.	Juno II (same as Pioneer III).	Dimensions: 20 in. long; 9 in. in diameter. Experiments: Measurement of radiation in space. Test photoelectric sensor in vicinity of Moon. Shell composition: Gold-washed fiberglass. Antenna: Cone itself serves as antenna; gold is conductor. Transmitter: 960.05 mc. at 180 mw. with 3 subcarriers. Power supply: Mercury batteries. Transmitter lifetime: About 90 hr.	Probe achieved its primary mission, an Earth-Moon trajectory, yielded excellent radiation data and provided a valuable tracking exercise. It is now orbiting the Sun. While the probe reached the vicinity of the Moon, it did not come close enough (20,000 miles) to trigger photoelectric sensor or sample Moon's radiation. The probe passed within 37,300 miles of Moon at 5:24 p.m. on Mar. 4, 1959. It passed 7.2° east and 5.7° south of Moon at 4,490 m.p.h. Probe reached perihelion, 91,700,000 miles, at 9 p.m. Mar. 17, 1959; scheduled to reach aphelion, 106,100,000 miles on Oct. 1, 1959. Injection velocity of 24,790 m.p.h. was 188 m.p.h. below planned velocity. Pioneer IV was tracked for 82 hr. to distance of 407,000 miles.	------	------
Discoverer I, United States: Satellite (cylinder). Total weight of satellite, 1,300 lb., including 245 lb. of instruments. Launched from Pacific Missile Range into polar orbit.	Feb. 28 to Mar. 5, 1959.	Thor-Hustler Standard Thor booster with a 2d stage designed to go into orbit. Both liquid fueled. Weight, about 108,400 lb. Height, 78.6 ft.	Dimensions: Length 19.2 ft., diameter 5 ft. Objectives: Check out propulsion, guidance, staging, communications. Antennas: 1 directional and 1 whip antenna. Transmitters: classified but included telemetry and tracking beacon. Power supply: Nickel-cadmium batteries.	Period: 95.9 min. Difficulty in stabilization caused tumbling which hampered consistent tracking acquisition. After about 5 days, it is presumed from tracking reports the satellite burned up on reentry into atmosphere at an unknown point. Inclination: 3° off north-south axis of Earth.	99	605
Discoverer II, United States: Satellite (cylinder). Total	Apr. 13 to Apr. 26, 1959.	Thor-Hustler (same as Discoverer I).	Dimensions: 2d stage same as Discoverer I but with a 195-lb recovery hemisphere-shaped	Period: 90.5 minutes. All equipment worked as programed	142	220

Discoverer II, United States: Satellite (cylinder). Total weight, 1,610 lb., including 245 lb. of communications and performance instrumentation and a 195-lb. capsule. Launched from Pacific Missile Range into polar orbit.	Apr. 13 to Apr. 26, 1959.	Thor-Hustler (same as Discoverer I).	Dimensions: 2d stage same as Discoverer I but with a 195-lb recovery hemisphere-shaped capsule measuring 33 in. in diameter by 27 in. deep. Capsule used small retro rocket to aid reentry. Experiments: To recover capsule; maintain temperature and oxygen sufficient to sustain life; emulsion packs to measure radiation. Antennas: 1 directional and 1 whip antenna. Transmitters: Classified but included telemetry and tracking beacon plus a tracking beacon in recovery capsule. Power supply: Nickel-cadmium batteries. Transmitter lifetime: Telemetry ran to Apr. 14 as planned; tracking beacon ran until Apr. 21 as planned. Capsule composition: Classified.	Period: 90.5 minutes. All equipment worked as programed except timer which ejected capsule. Timer difficulty made capsule impact in vicinity of of Spitzbergen Islands Apr. 14 instead of Hawaii vicinity where it was to be recovered either by airplane or ship. Capsule, which contained radiation emulsion packs, has not been found. Temperature-oxygen instruments showed life could be supported. Inclination: 0.2° off north-south axis of Earth.	142	220
Vanguard, United States: 2 satellites. Total weight of scientific payloads, 23.3 lb.	Apr. 13, 1959–0..	Vanguard SLV 5 (same as TV 3).	Dimensions: Vanguard 3A—13-in. ball with a 17 ½-by 2½-in. cylinder extending from it. Vanguard 3B—a 30-in. inflatable sphere containing no instrumentation to be tracked optically. Experiments: Vanguard 3A contained a precise magnetometer to be used to map Earth's magnetic field. Vanguard 3B was to measure drag in space. Composition: 3A was made of fiberglass and phenolic resins. 3B was laminated aluminum foil and plastic sheet. Transmitters: For 3A—108 mc. at 10 mw. for tracking and 108.03 mc. at 80 mw. for telemetry on ground command. Power supply: Silver-zinc batteries. Antennas: 4 spring-lock rods.	2d stage failed to operate properly which caused a tumbling motion. Payload and 3d stage fell into Atlantic Ocean several hundred miles off Cape Canaveral. Total flight time, about 500 sec.	0	0

[1] Except where indicated, this chart does not include description and weights of spent rocket casings, etc., that have gone into orbit or flight trajections along with payloads.
[2] All distances are given in statute miles above the surface of the Earth.
[3] Altitude: 40,000 to 70,000 ft.
[4] Altitude: About 70, 700 statute miles.
[5] Altitude: 963 miles.
[6] Altitude: 63,580 miles.
[7] These are unofficial figures culled from U.S. press, Pravda, and Moscow radio.

NOTE.—All statistics listed above, with exception of the Russian figures, are official. Statistics from here on are subject to updating when study of data has been completed.

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